

MAESTRO: A new facility for ARPES at the ALS

Aaron Bostwick

E. O. Lawrence Berkeley National Laboratory

Principal Investigators

Eli Rotenberg, ALS-LBNL

Alessandra Lanzara, U.C. Berkeley Physics

Collaboration

A. Bansil, Northeastern U.

Berkeley

D. Dessau, U. Colorado

Wisconsin

S. D. Kevan, U. Oregon

Z. X. Shen, Stanford U.

Investigators:

M. Crommie, U.C.

F. J. Himpsel, U.

J. Mitchell (ANL)

LBNL Facility Collaborators*:

A. Bostwick (ALS)

Z. Hussain (ALS)

E. Anderson (CXRO)

J. Bokor (MF)

T. Warwick (ALS)

M. Salmeron (MF)

D. Attwood (CXRO)

Summary

- One half of a chicaned sector 7 at ALS (other half is COSMIC)
- MAESTRO will include a new:
 - the next-generation nanoARPES chamber for nanometer-scale photoemission.
 - new beamline optics for sector 7, optimized for delivery of photons with sufficient flux and energy resolution to achieve down to 50 nm spot size.
 - a sample transfer system to existing preparation/characterization chambers.
- MAESTRO also integrates existing growth and characterization tools from the existing ESF facility:
 - the existing μ ARPES endstation, which will probe down to ~ 10 μm sample size.
 - the existing crystal growth chambers (MBE and laser-based).
 - a new PEEM, already funded, to be acquired in FY11.

MAESTRO Timeline

2004-2005 - Groundwork

- Off-site Retreats, 2004

- Photoemission Review, 2005

- Workshop October 2005

- Adopted as part of “wave 1” of the ALS strategic plan

2005-2007 -Phase-I nanoARPES

- LDRD funding FY05-07

- ~300 nm demonstrated FY05

- Dec 2005, White Paper Submission to DOE

- DOE Mid-range Instrumentation Program \$5M

- May 17 2006 preproposal

- Aug 30 2006 proposal submitted - Midrange program cancelled

2008-2009 Continued LDRD support

refinement of detector design

DOE SISGR Midrange program \$5M

- Aug 30 2008 preproposal

- April 2009 proposal submitted

- July 15, 2009 proposal accepted

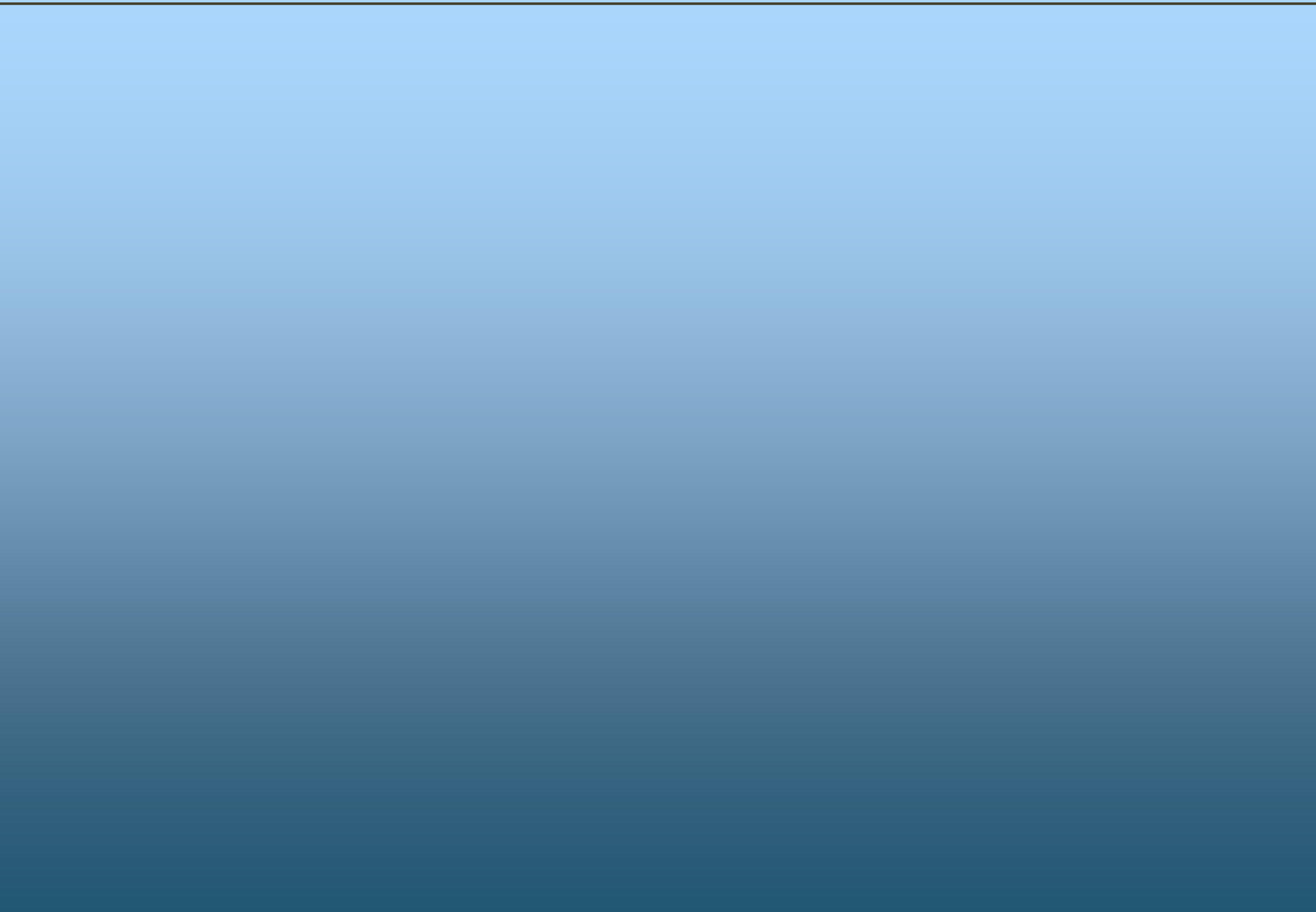
Funded October 2009

Design and fabrication now is underway

Existing BL7 decommissioned early 2012

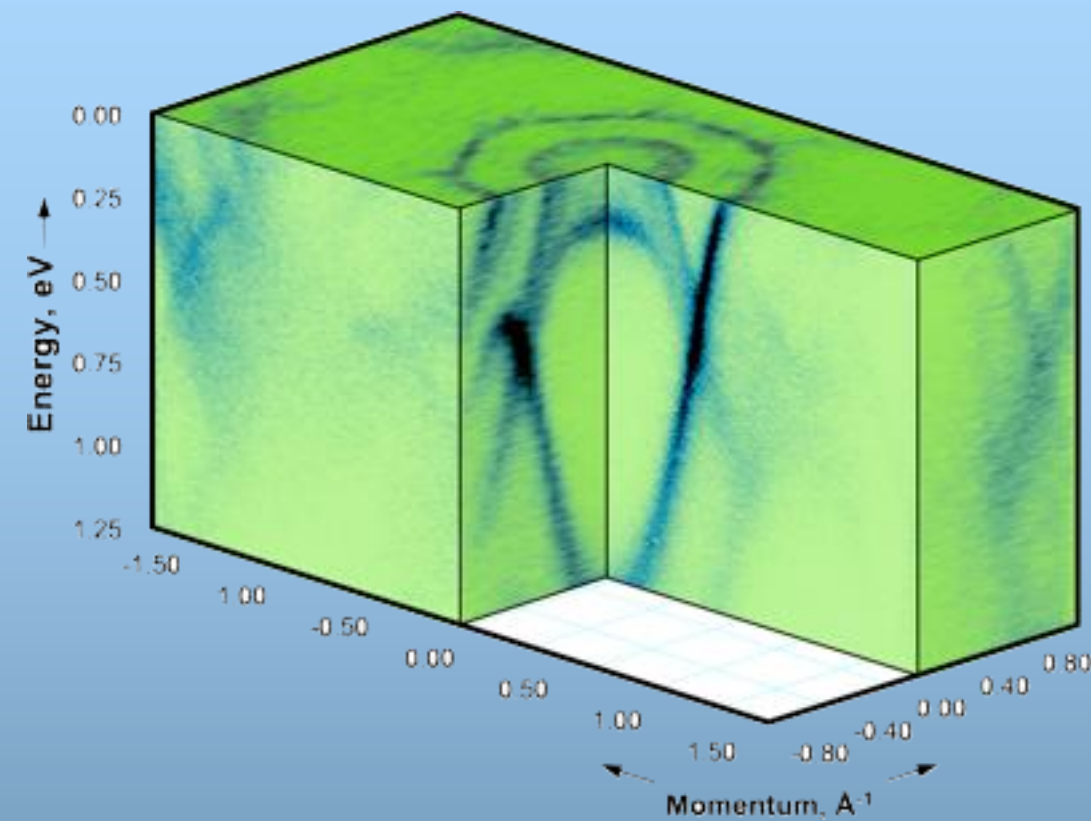
MAESTRO commissioning begin late 2012

Users mid 2013?



Conventional ARPES

QuickTime™ and a
Video decompressor
are needed to see this picture.



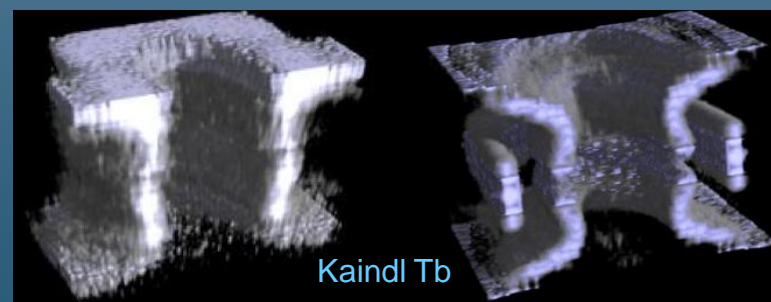
Gd valence band
3 minutes

TiTe₂
16 minutes

180 minutes: E vs (k_x, k_y, k_z, T)

T=200K

T=20K



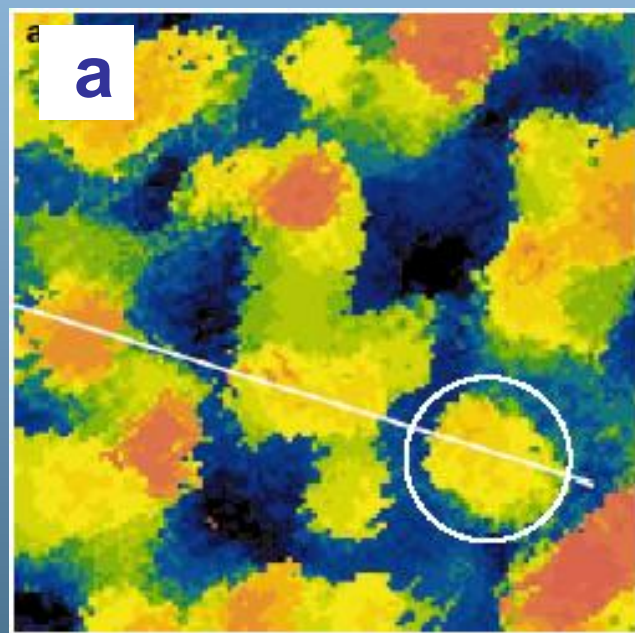


Why go Nano?

Example: Correlated Materials

Doped Mott-Hubbard Insulators
Universal Spatial Fluctuations?

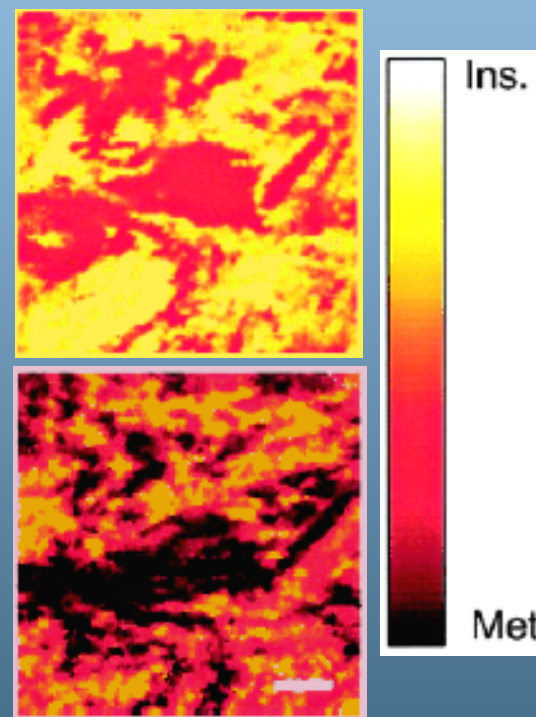
High T_c Superconductor
Bi-2212



15 nm²

Lang et al
Nature v415,412 (2002)

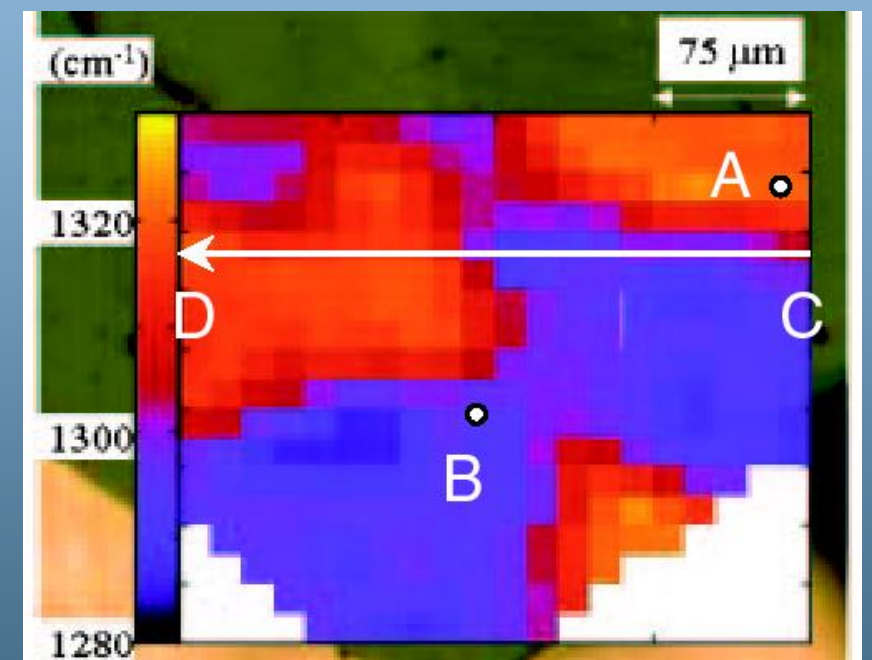
CMR Material
LCMO



610 nm²

Fath et al
Science v285,1540 (1999)

Organic Superconductor
k-(BEDT-TTF)₂Cu[N(CN)₂]Br

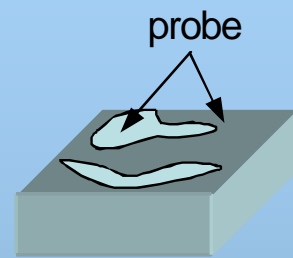


3000 nm²

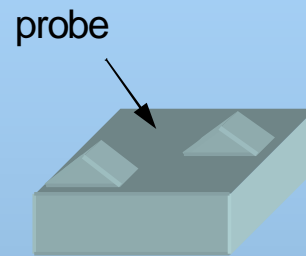
Sasaki et al
J. Ph. Soc. Japan v74,2351 (2005);
PRL v92,227001 (2004)

Why go Nano?

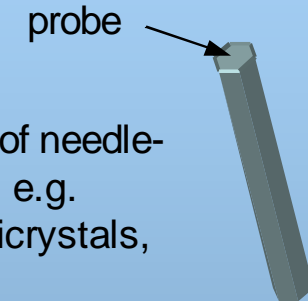
Many interesting samples are very small.



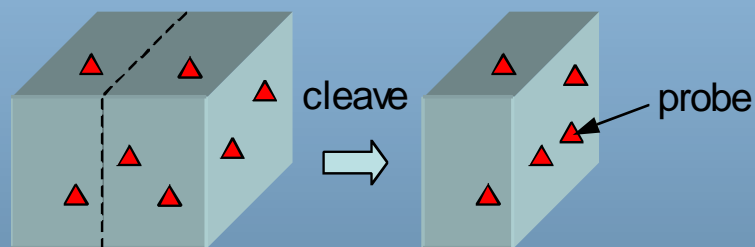
(a) phase separation
- doped Mott insulators
- magnetism



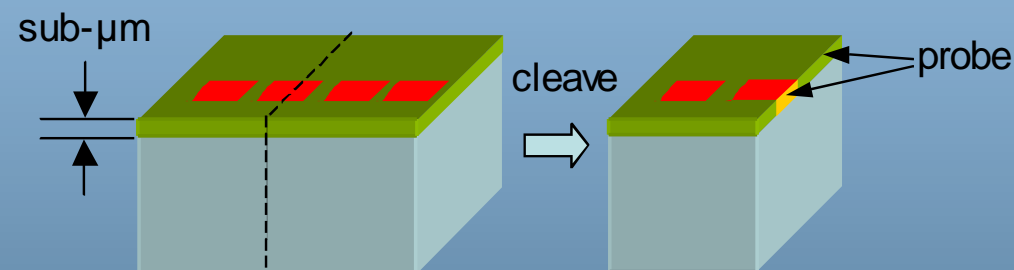
(b) isolating flat regions of
irregular cleaves



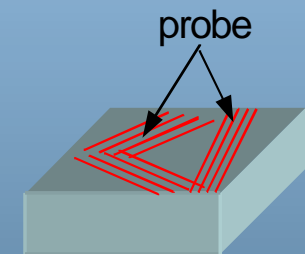
(c) 2-d plane of needle-
like samples, e.g.
 NbSe_3 , quasicrystals,
etc



(d) microcrystallites embedded
in a host material for cleavage



(e) thin films grown ex situ;
also quantum dots, other nano-
engineered devices



(f) isolating mixed phases
on epitaxial film surfaces

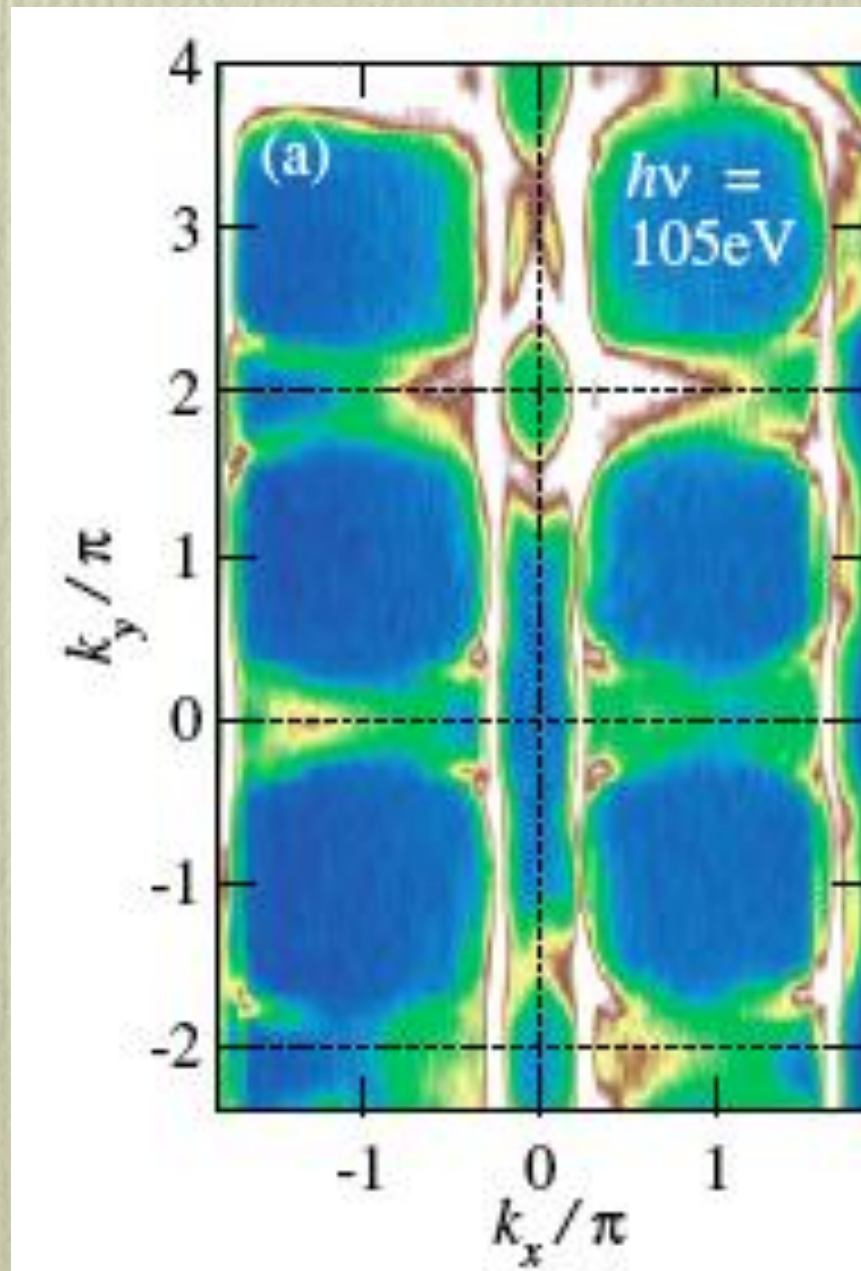
- Presently, state-of-the-art resolution is around $20\ \mu\text{m}$



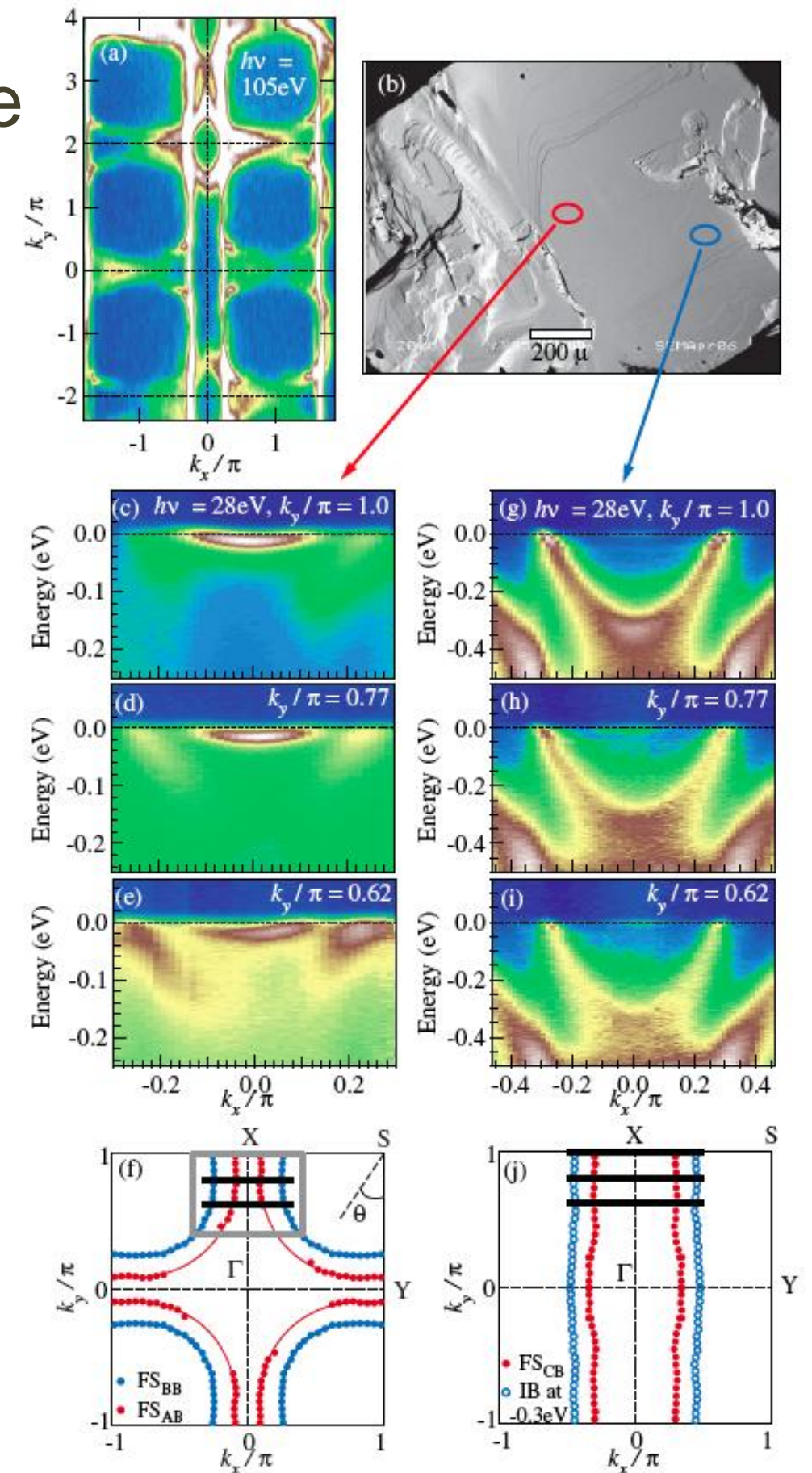
Why go Nano?



Even some homogenous samples have structure when cleaved.

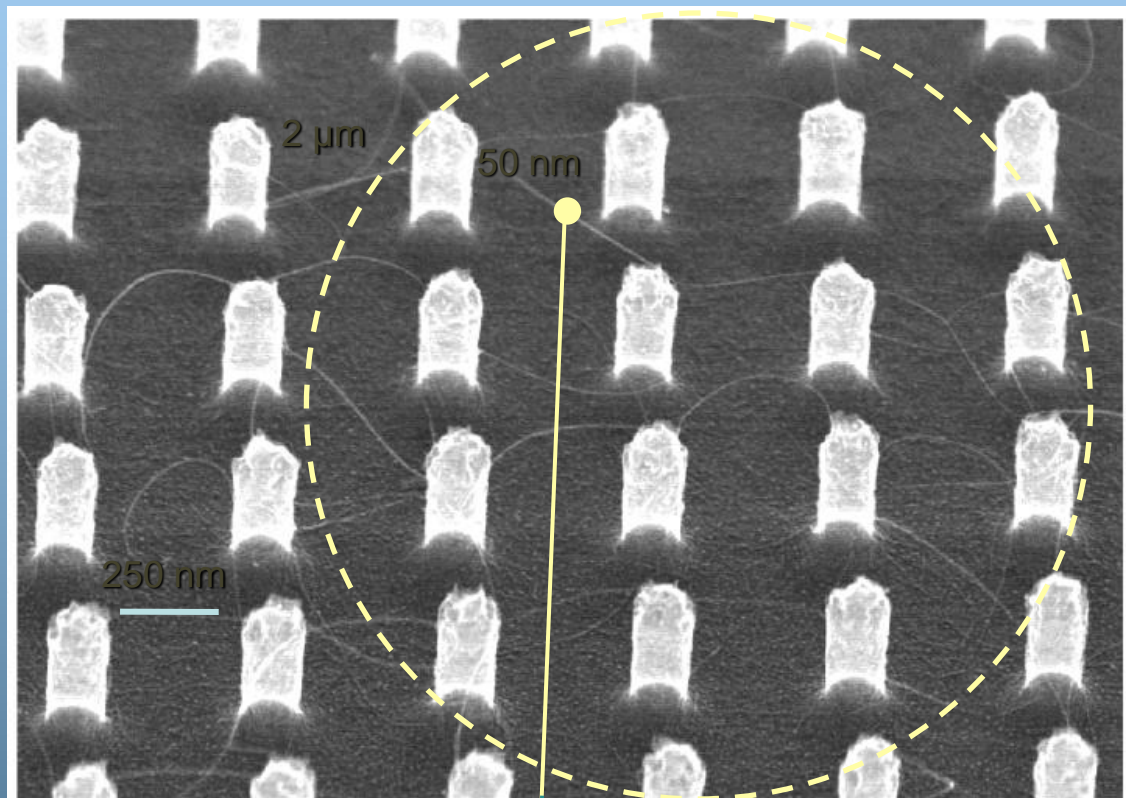


Kaminski PRL

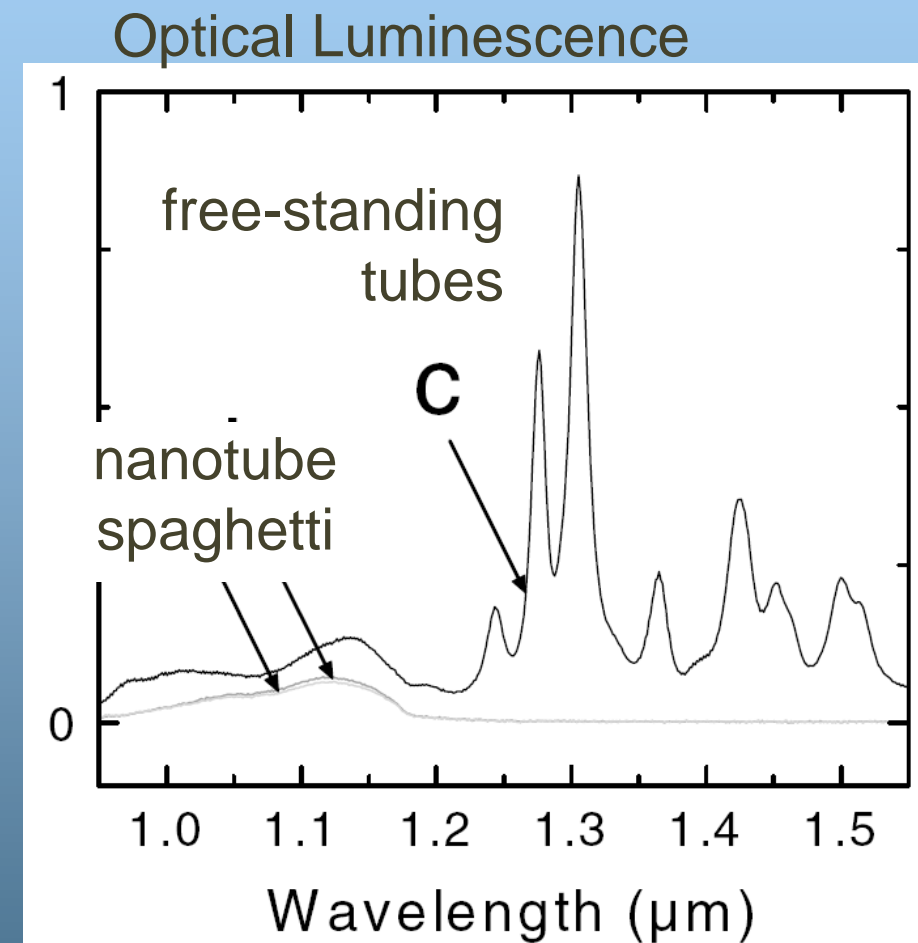


Another example: Single nanotube

Free-Standing Single-wall Nanotubes between Pillars



We could look at individual nanotubes (strained and unstrained) with our probe.



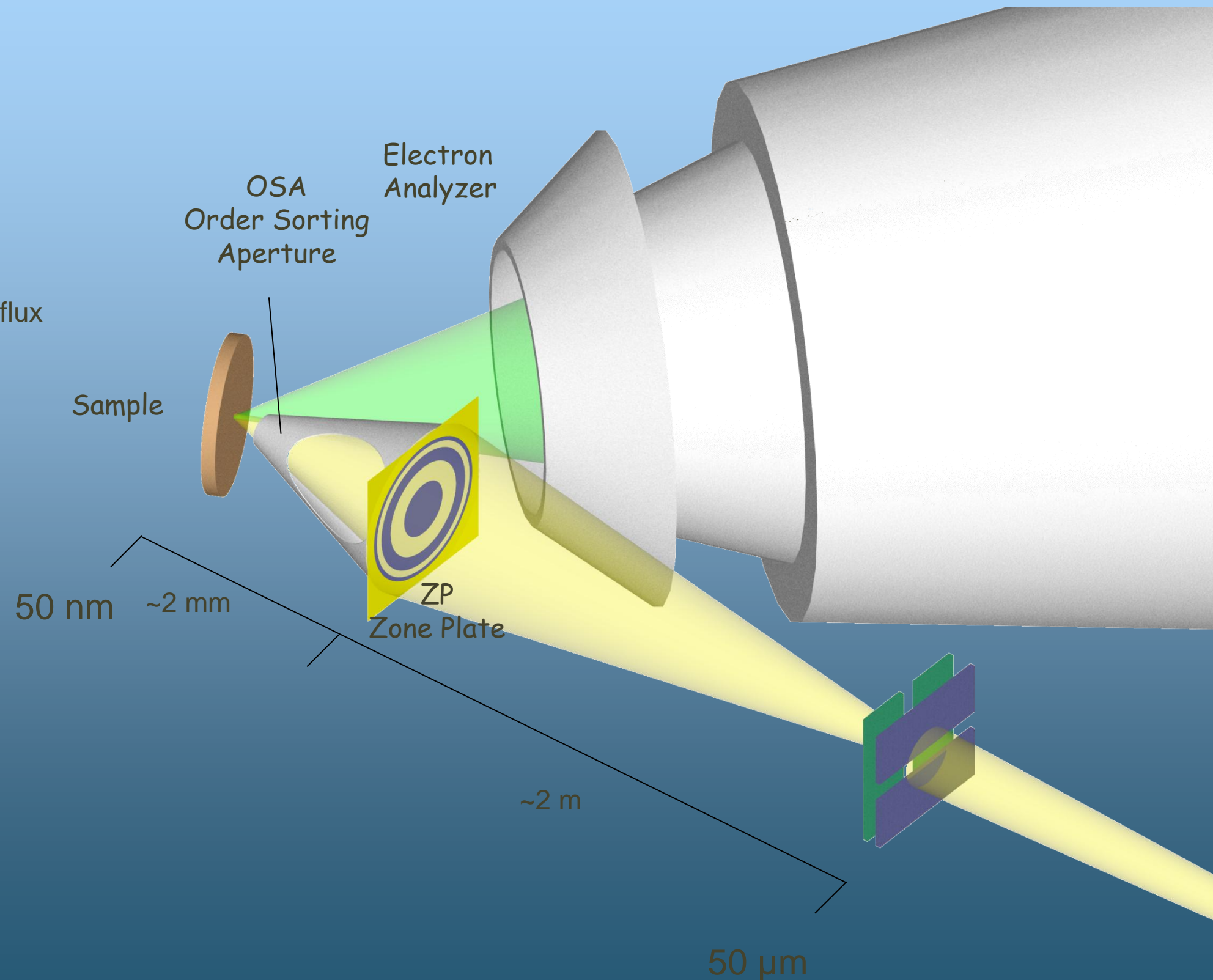
nanotubes must be isolated from each other and the substrate

how does nARPES work?

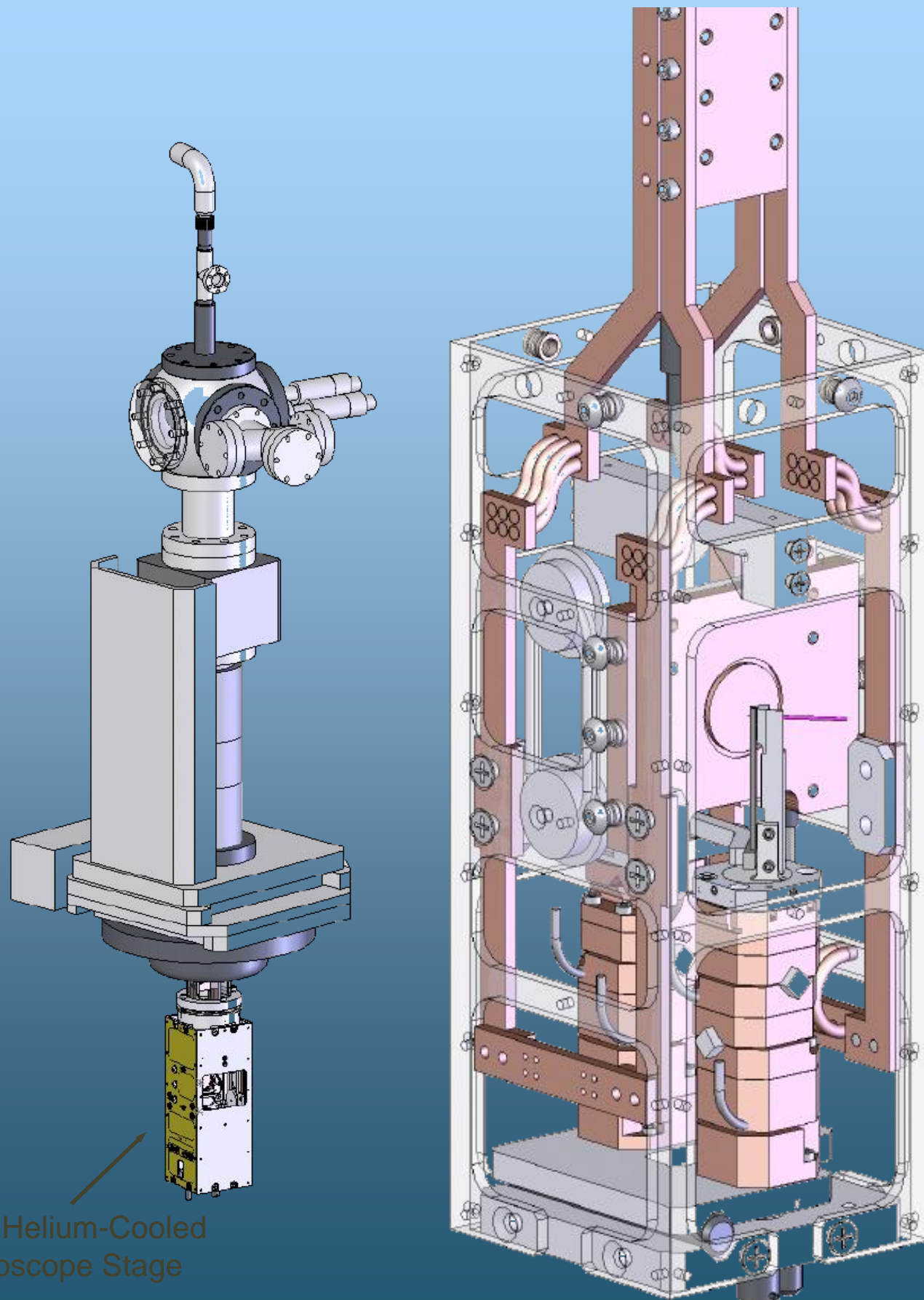
The zone plate acts as a lens with up to ~10% efficiency.

The ZP collects the coherent fraction (about 10% of total flux)

~0.1 - 1 % of conventional ARPES flux

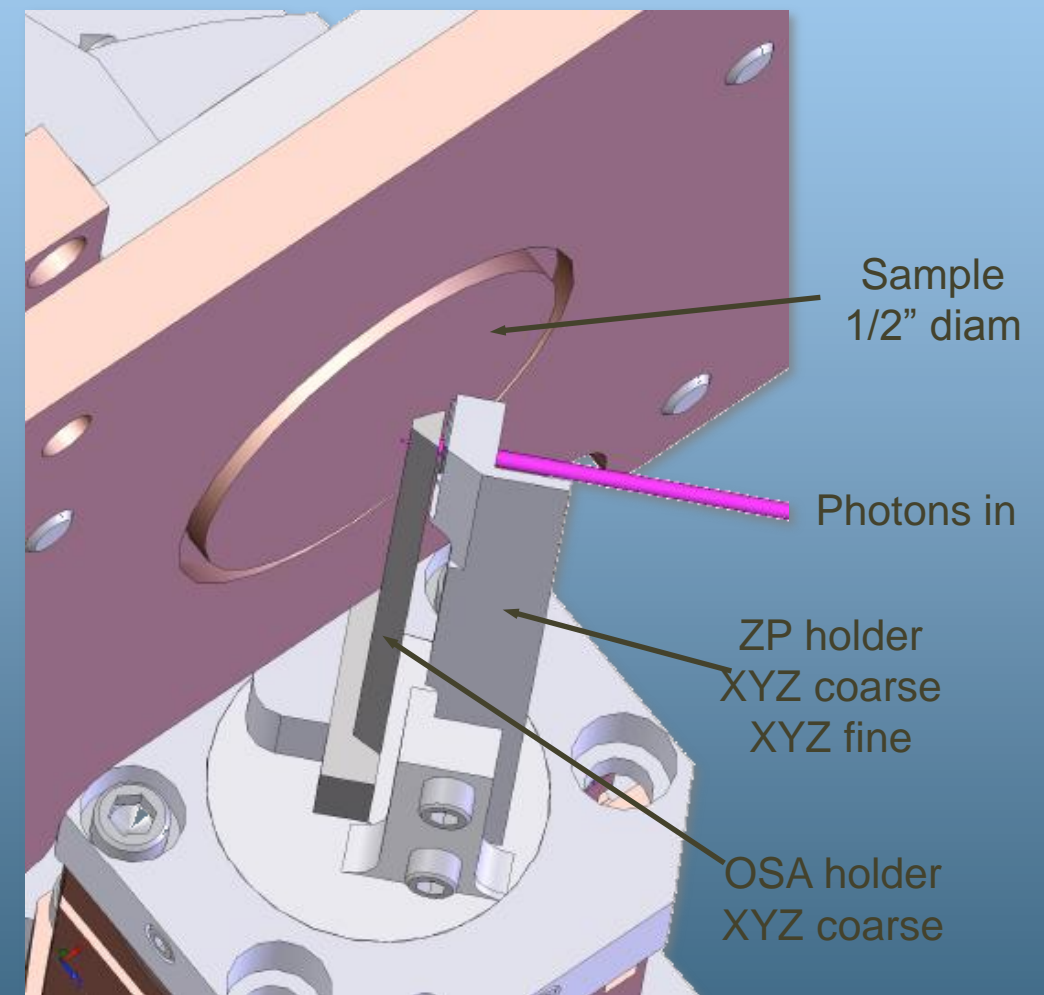


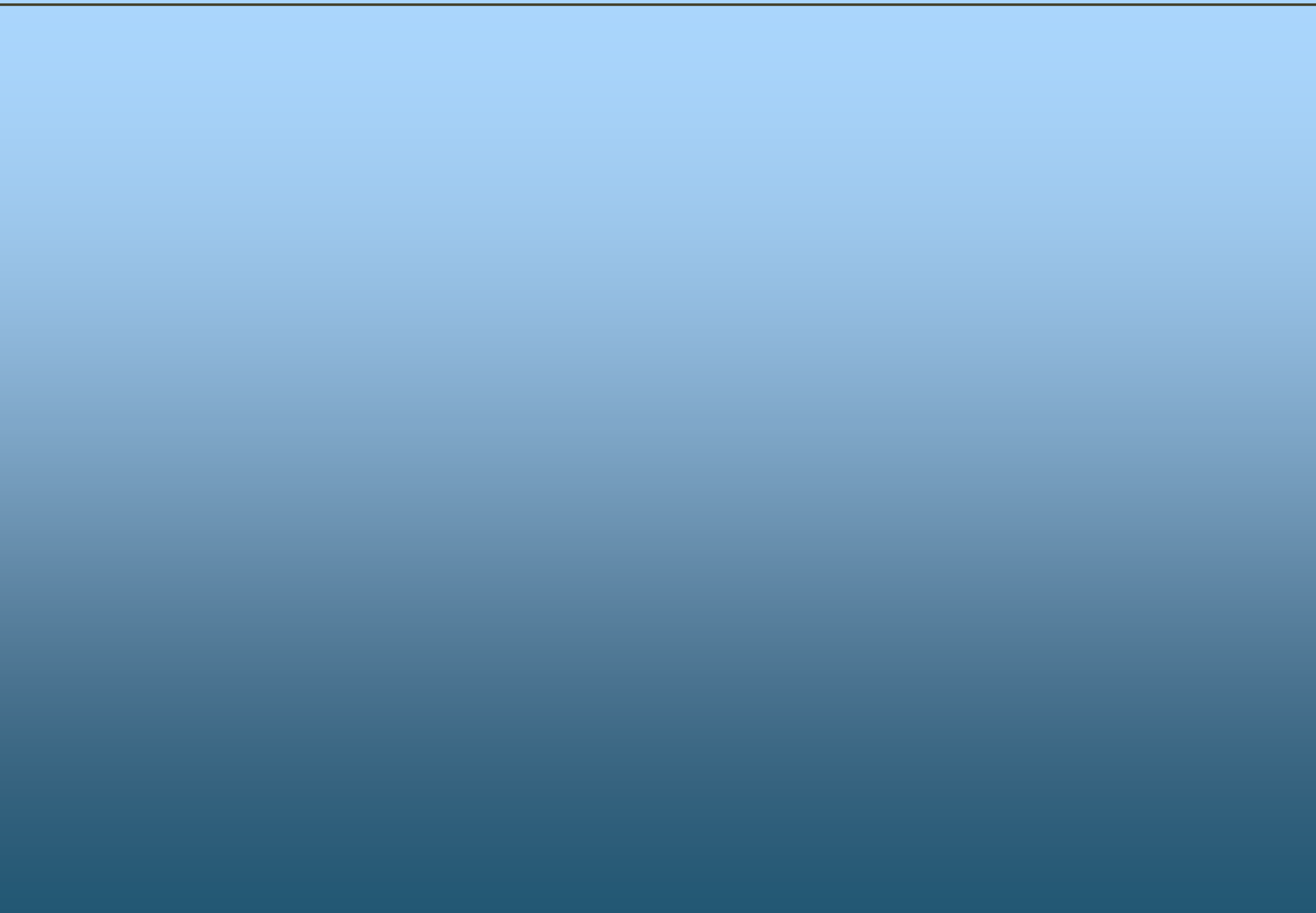
Test Instrument



Liquid Helium-Cooled
Microscope Stage

Down to 300 μm working distance

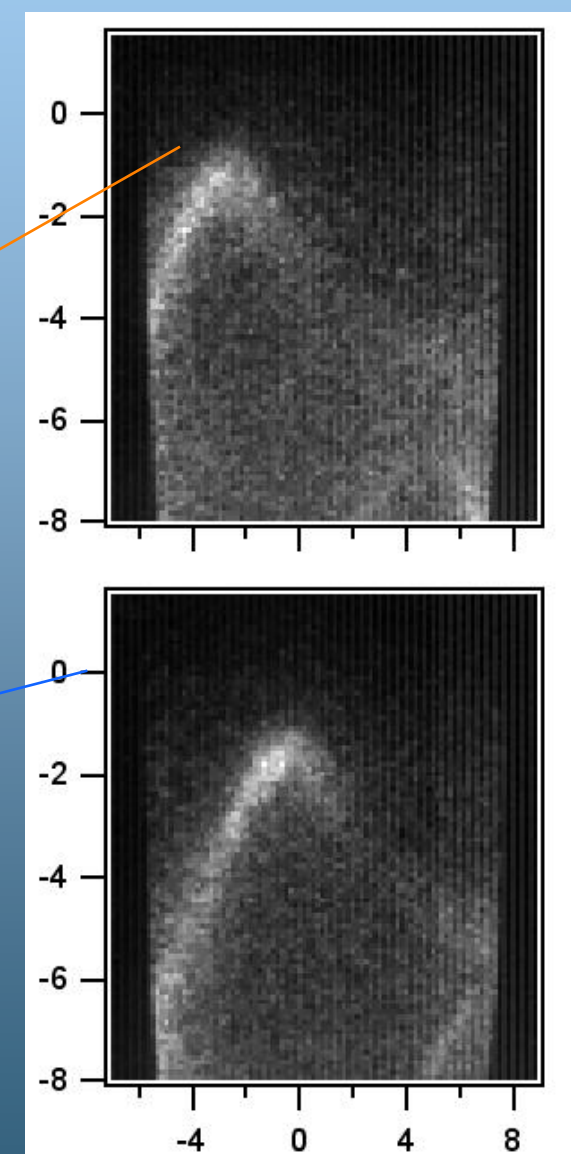
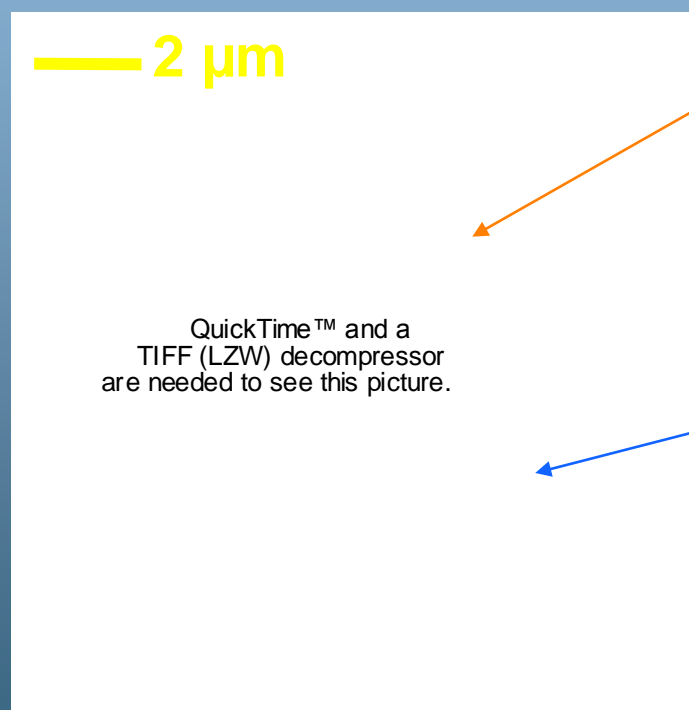
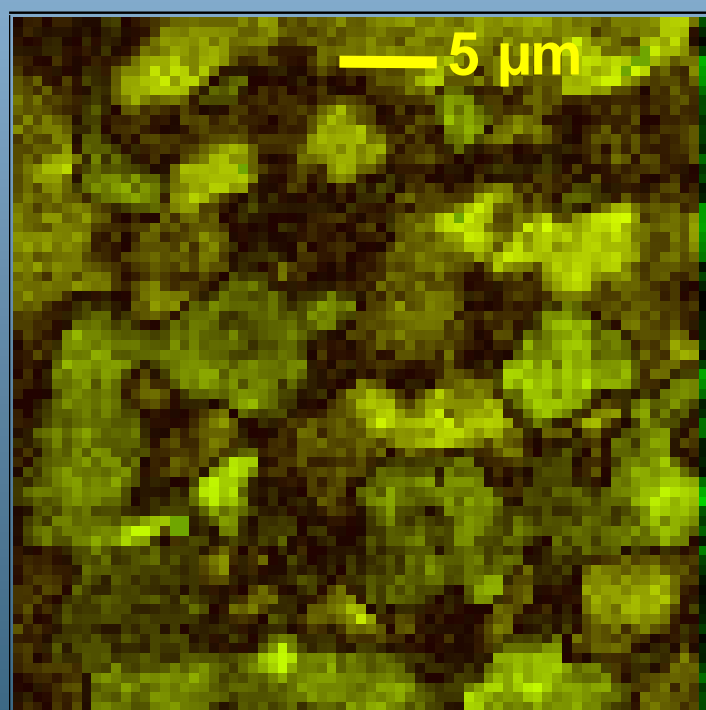


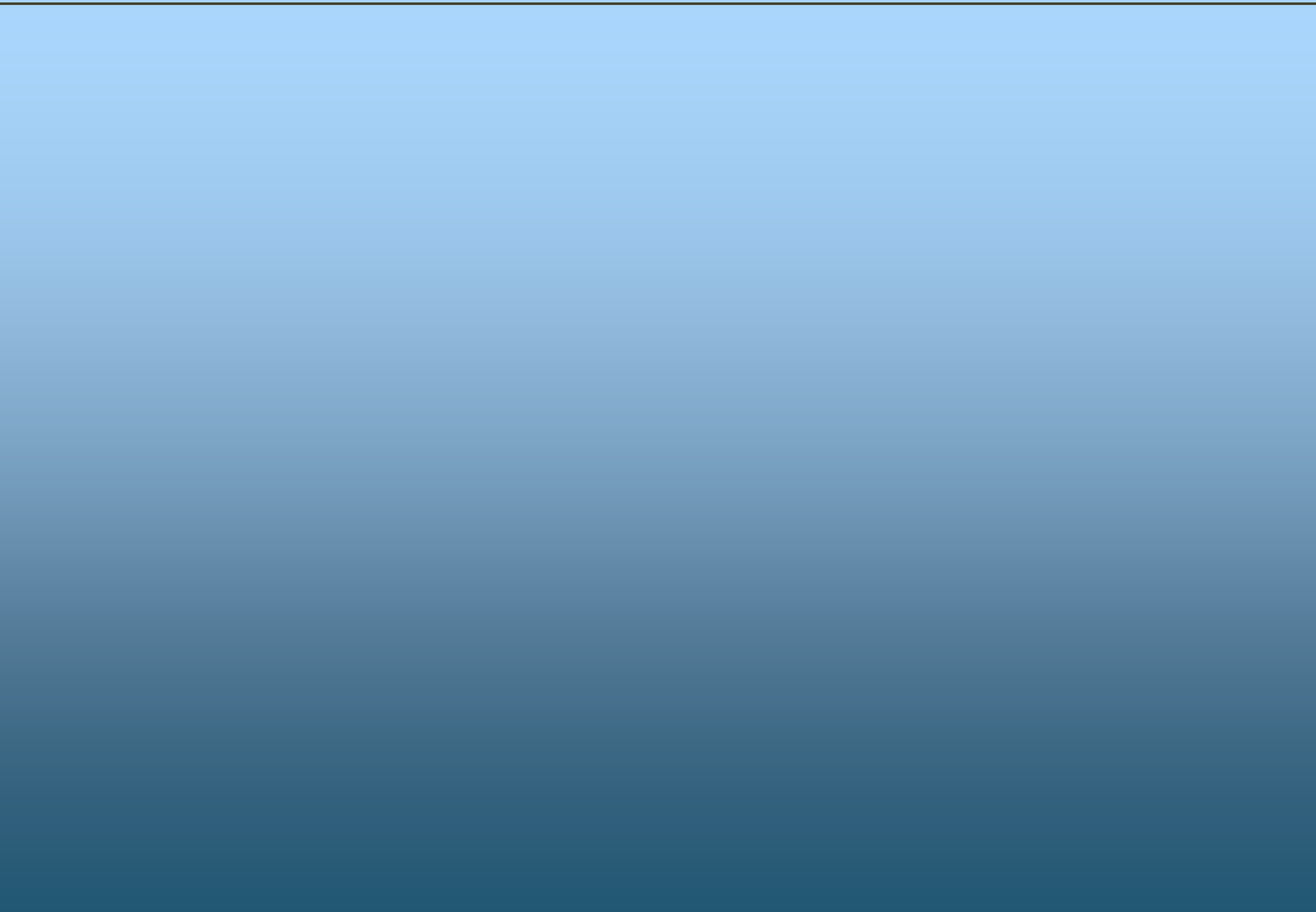


nARPES test results

Resolving the bands from a polycrystalline sample

HOPG graphite







Other contrast modes

- We want to build a new microscope whose contrast mechanisms are derived from the ARPES technique

Source	Category of measurement	What we can learn
Valence Electrons	Low resolution ARPES	Band Structure and Fermi Surface k-dependent susceptibility
	High Resolution ARPES	Mean Free Path λ Electron Lifetime τ Fermi Velocity v_F Drude Conductivity σ Coupling Constants Mass Renormalization Eliashberg Function Spectral Function
	Circular Dichroism	Time Reversal Symmetry Breaking Magnetism
	Linear Polarization Control	Band Symmetry (parity)
Core Levels	Chemical States Photoelectron Diffraction Circular Dichroism	Surface core level shifts Oxidation State Doping level Lattice Structure Magnetic Domain Imaging
Secondary Electrons	Total or Partial Yield	Topographical Contrast Absorption Contrast

Hard Work

Get these
for free!
(SPEM)

space charge effect?

Numerical Simulation

Back-of-the-envelope calculation

storage ring bunch length	t	60 psec
electron velocity	v	6×10^6 m/s
cloud radius	$r=vt$	300 μ m
electron total yield [nA]	I	8 nA
electron total yield [e ⁻ /s]	f	5×10^{10} e ⁻ /s
ALS repetition rate	ν	500 MHz
# electrons per bunch	$n=f/\nu$	100 e ⁻
distance between electrons	$d=r/n$	3 μ m

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

It pays to be old and slow

	bunch length, psec
ALS	65
CLS	65
Soleil	14
BESSY-II	18
SPEAR-III	16
NSLS-II	12 [?]

Conclusion:

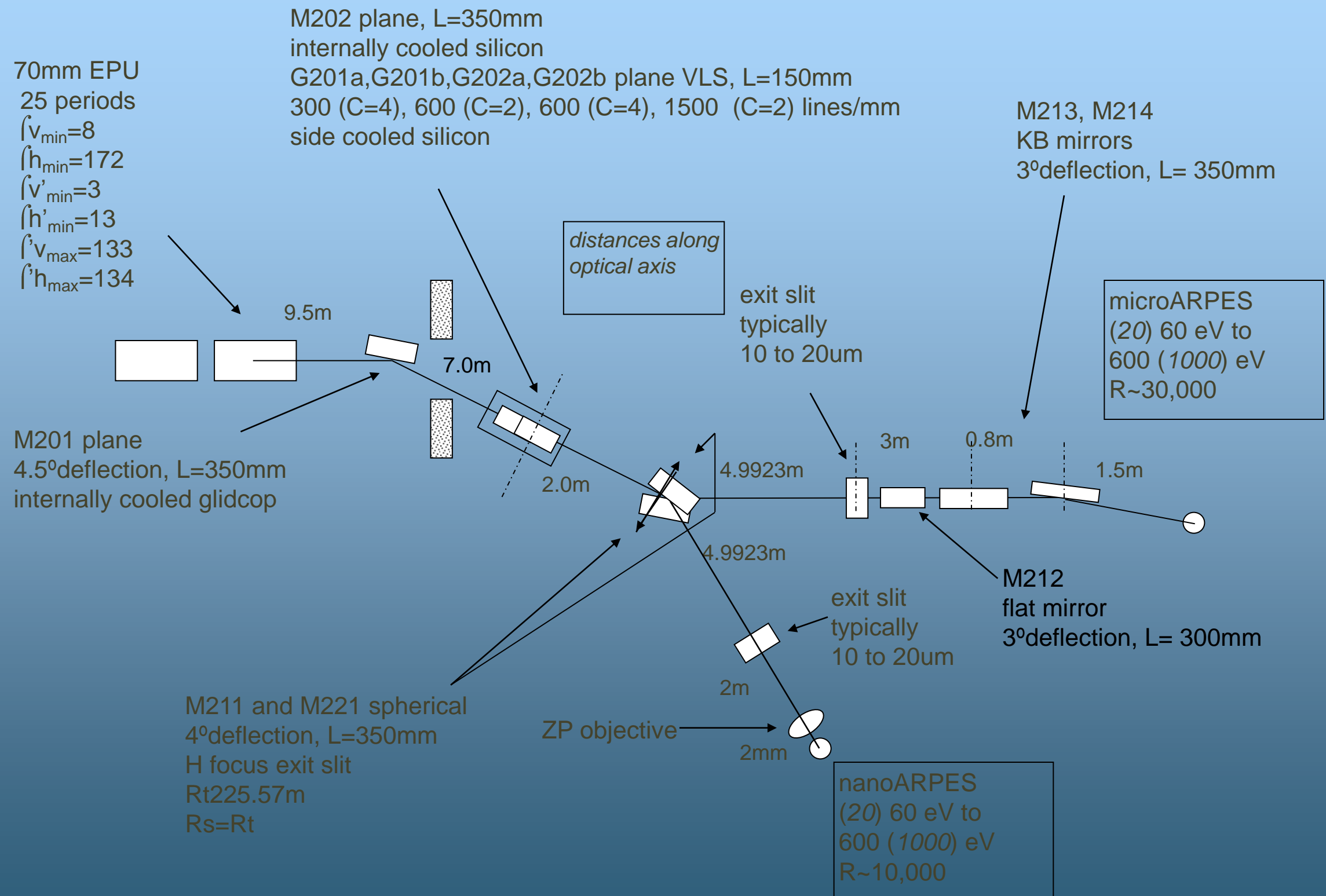
- 60 psec ALS pulses
- characteristic charge cloud ~ 3 μ m
- below this length scale, no sensitivity to spot size



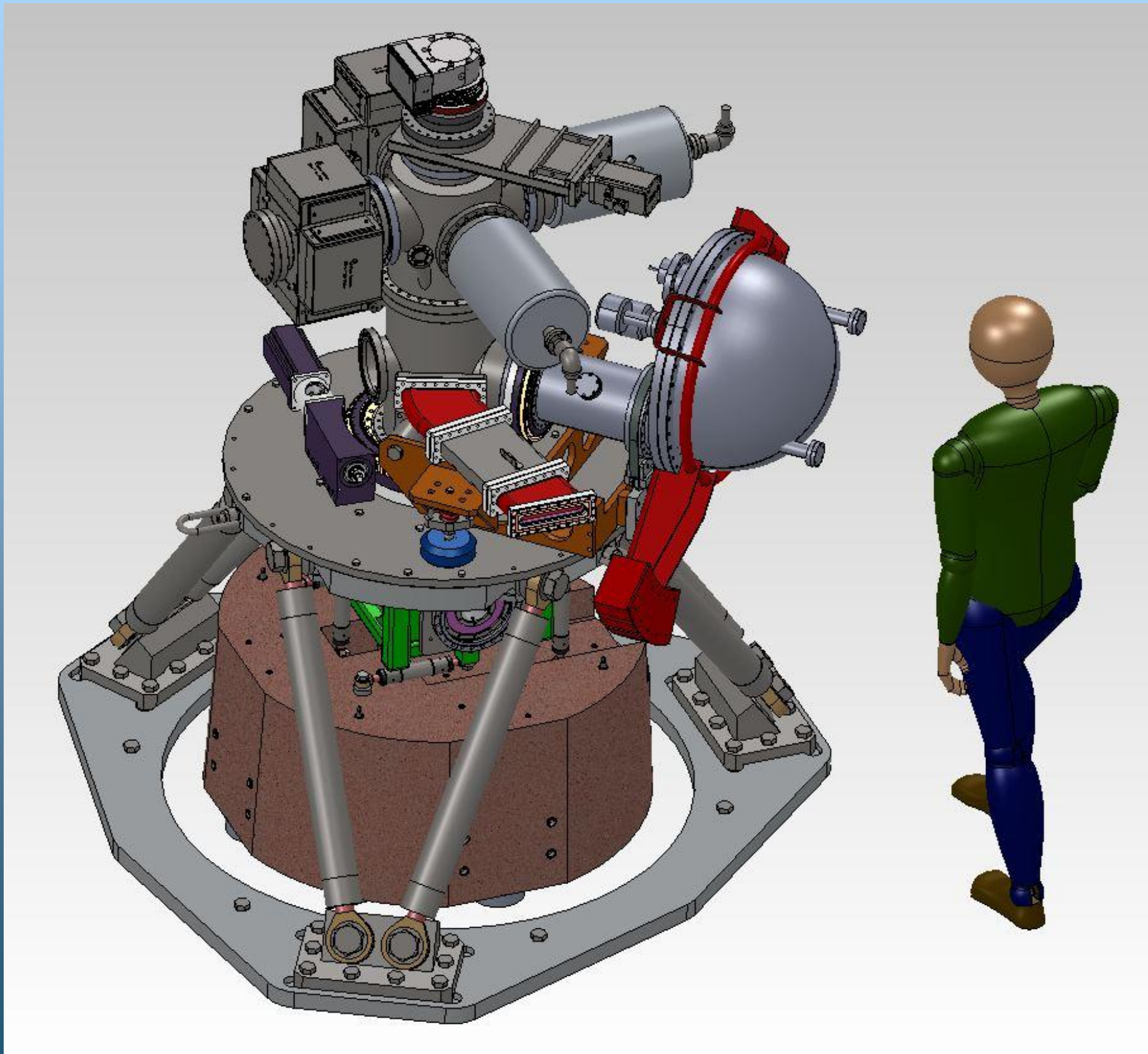
Beamline Specifications

- μ ARPES
 - 60-600 at 30,000 RP
 - 20-60 at 2meV
 - 600-1000 best effort
 - optimized flux at 10,000 RP
 - 10x10 μ m spot size
- nARPES
 - 60-600 at 10,000 RP
 - optimized for coherent flux at 95eV at 50nm spot size at 10k RP
 - trade spectral and spatial resolution for flux

Beamline Design

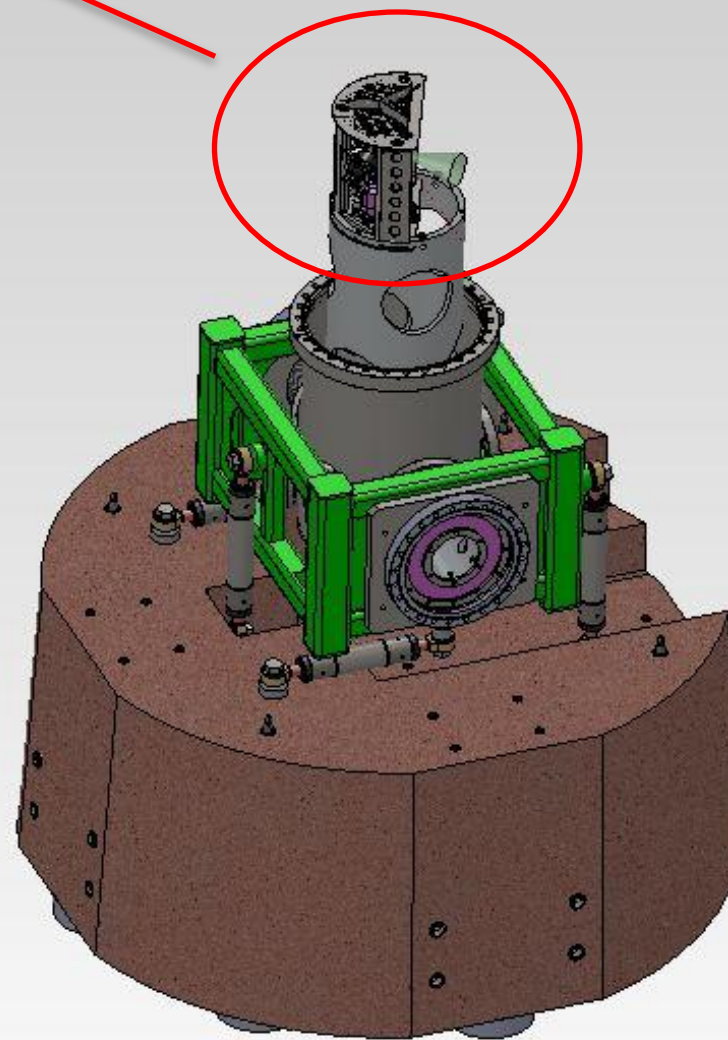


nARPES endstation

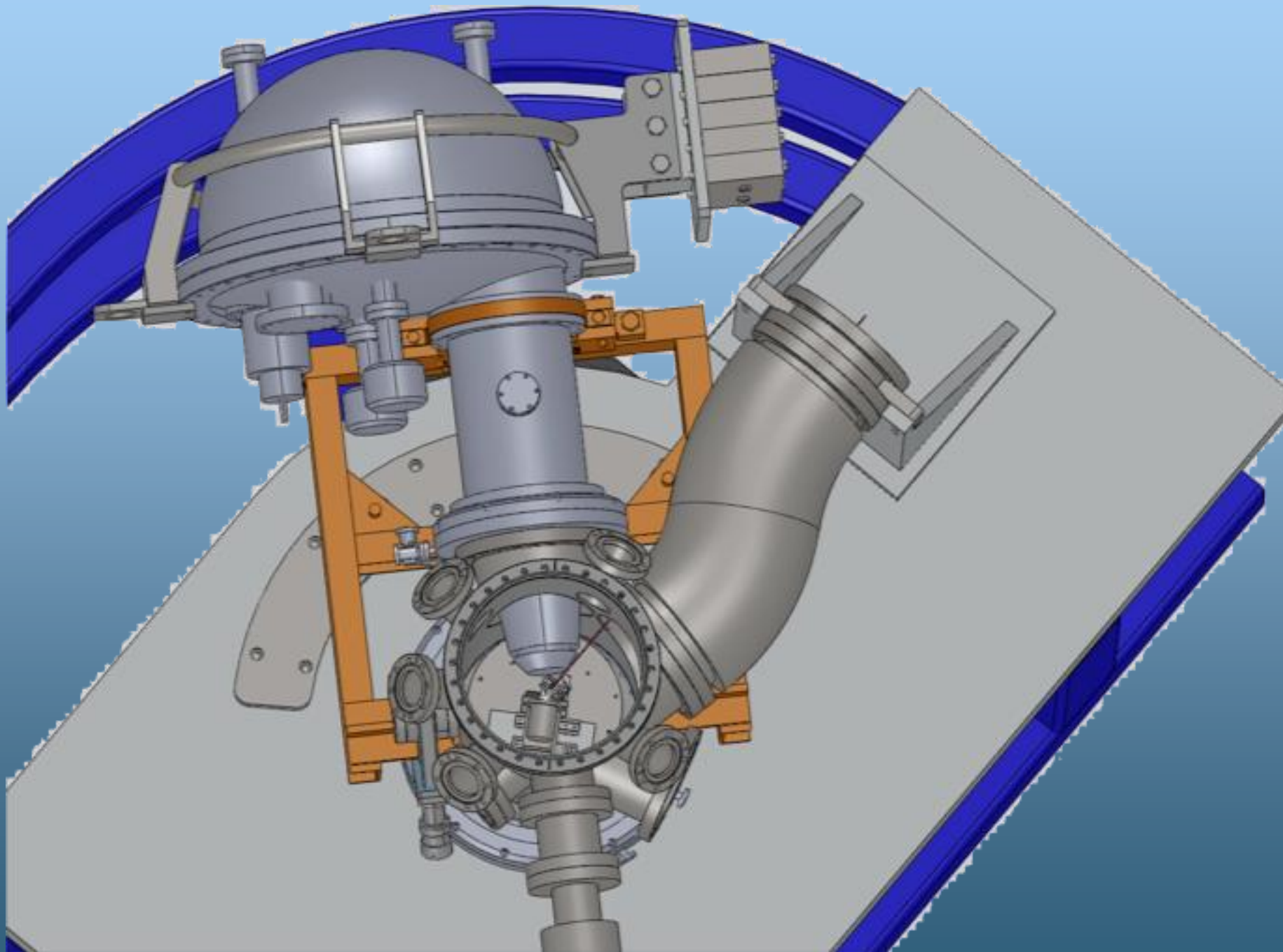


nARPES endstation

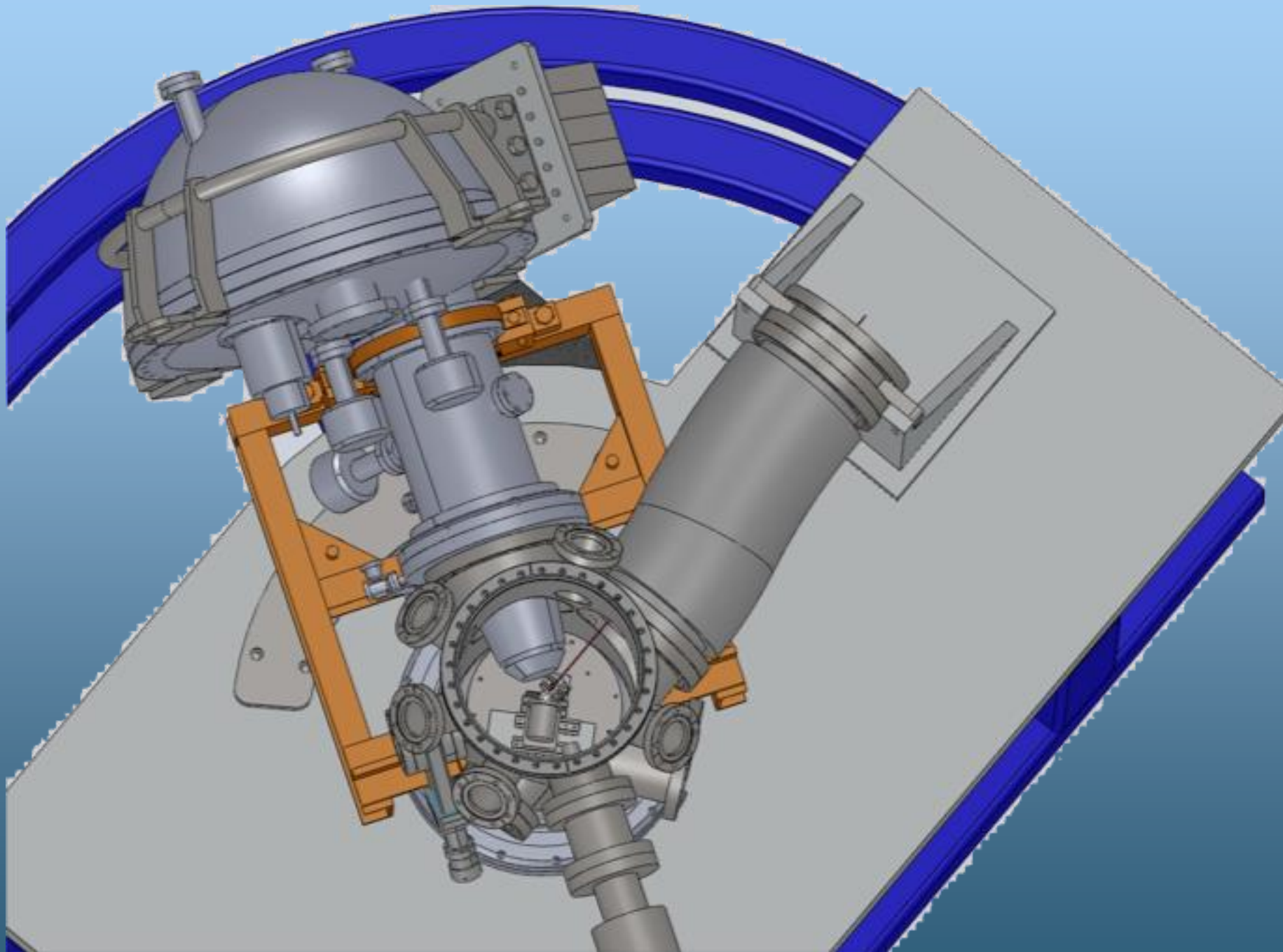
sample & optics module



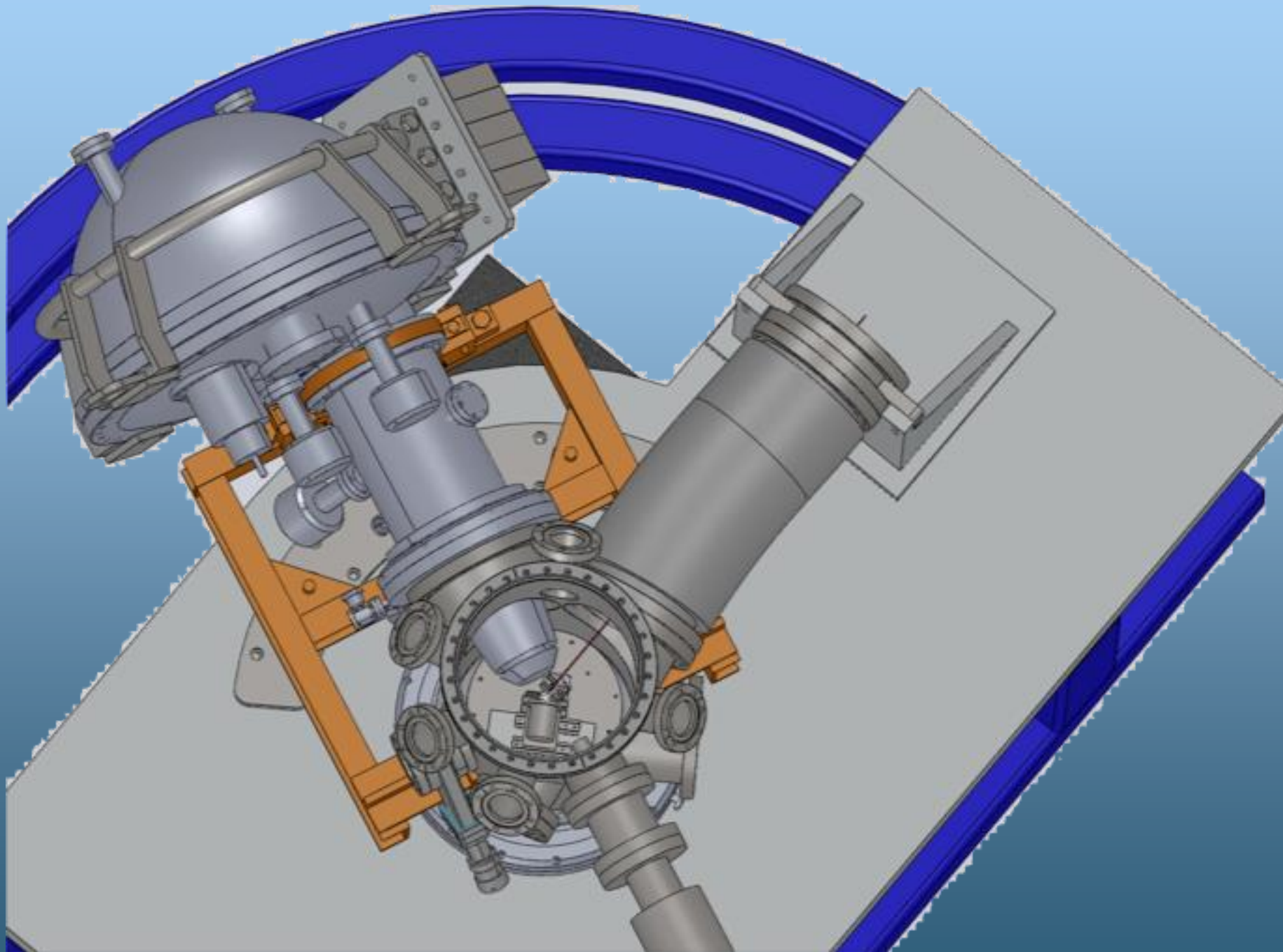
Chamber Rotation



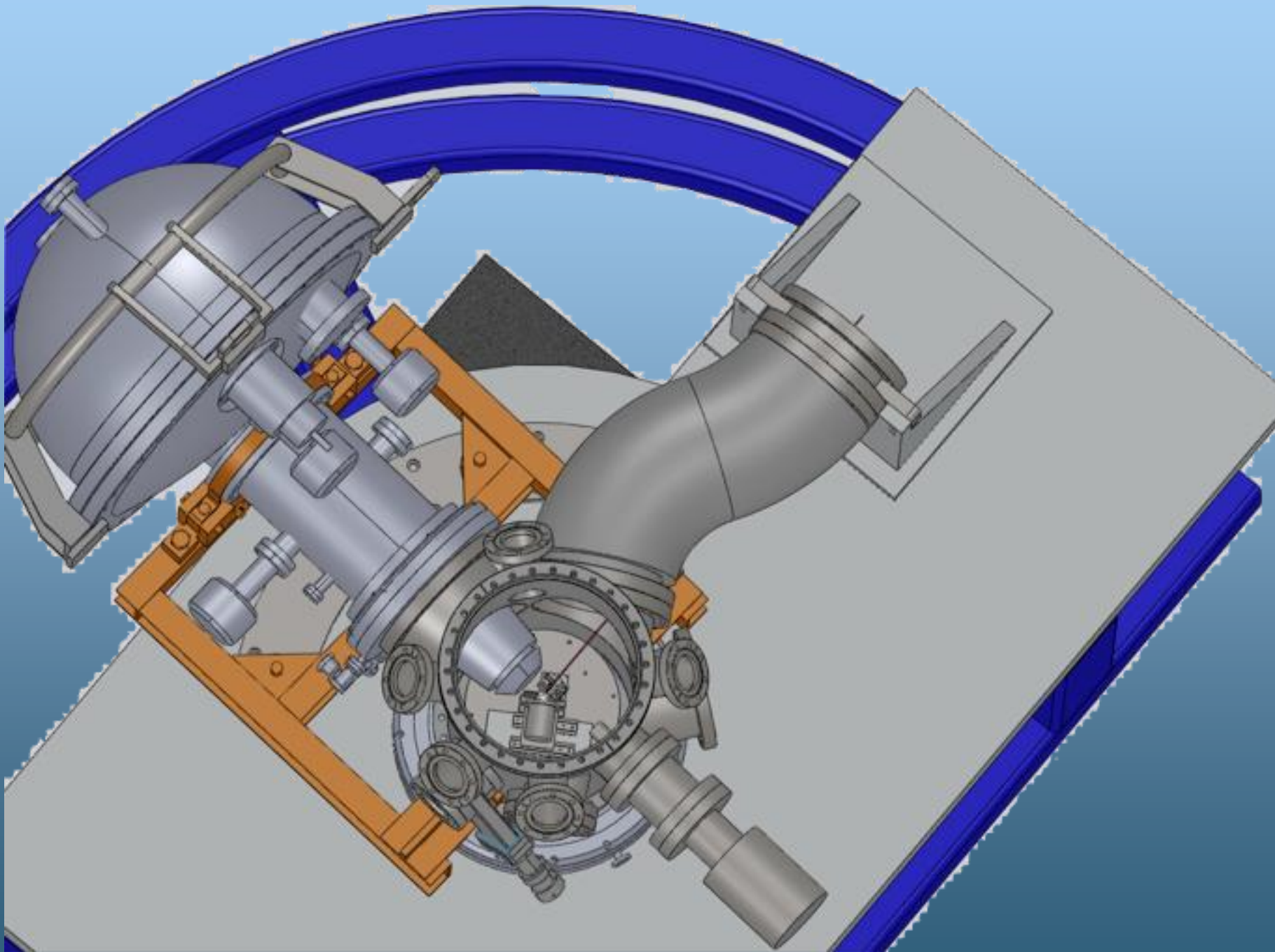
Chamber Rotation

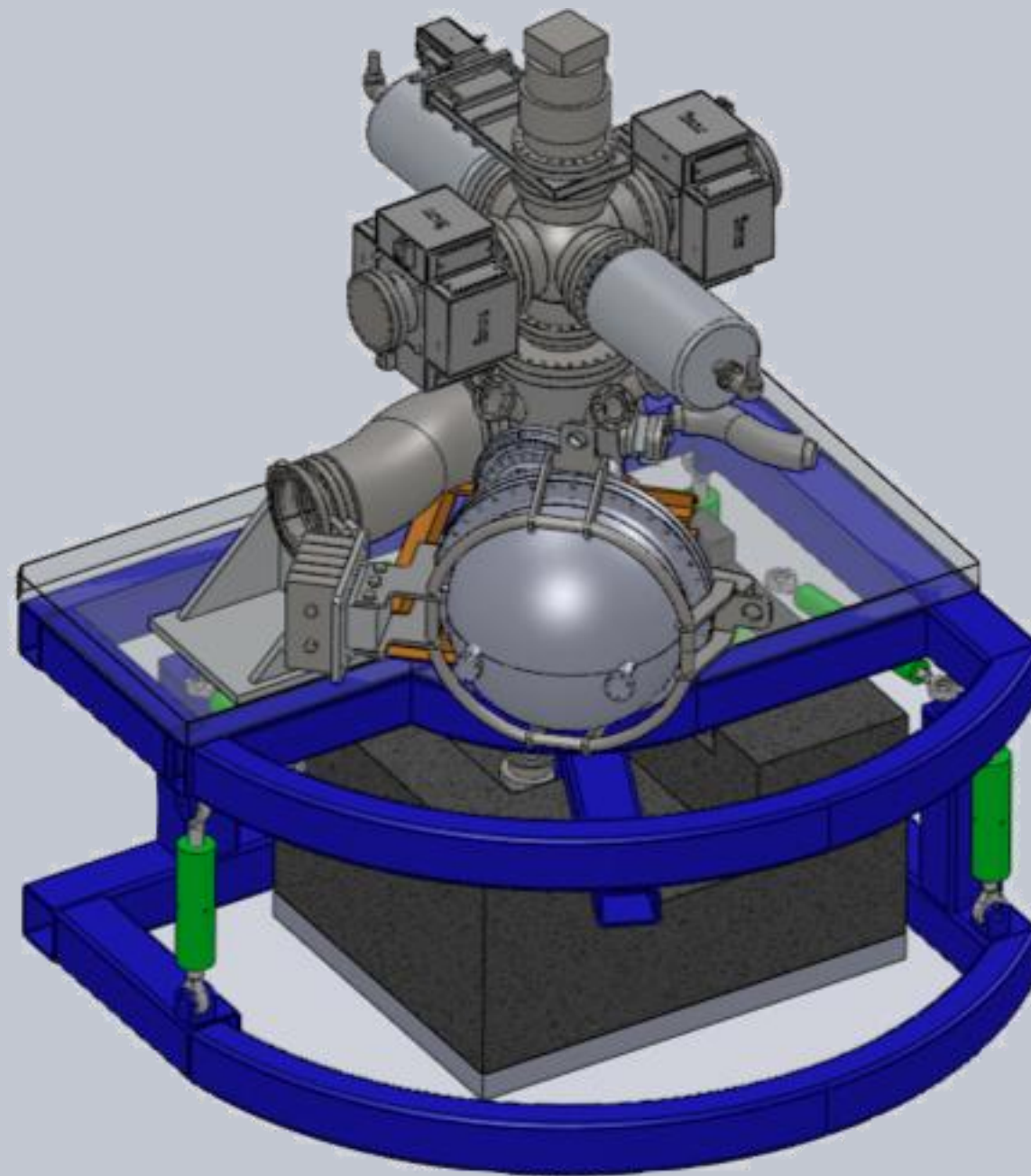


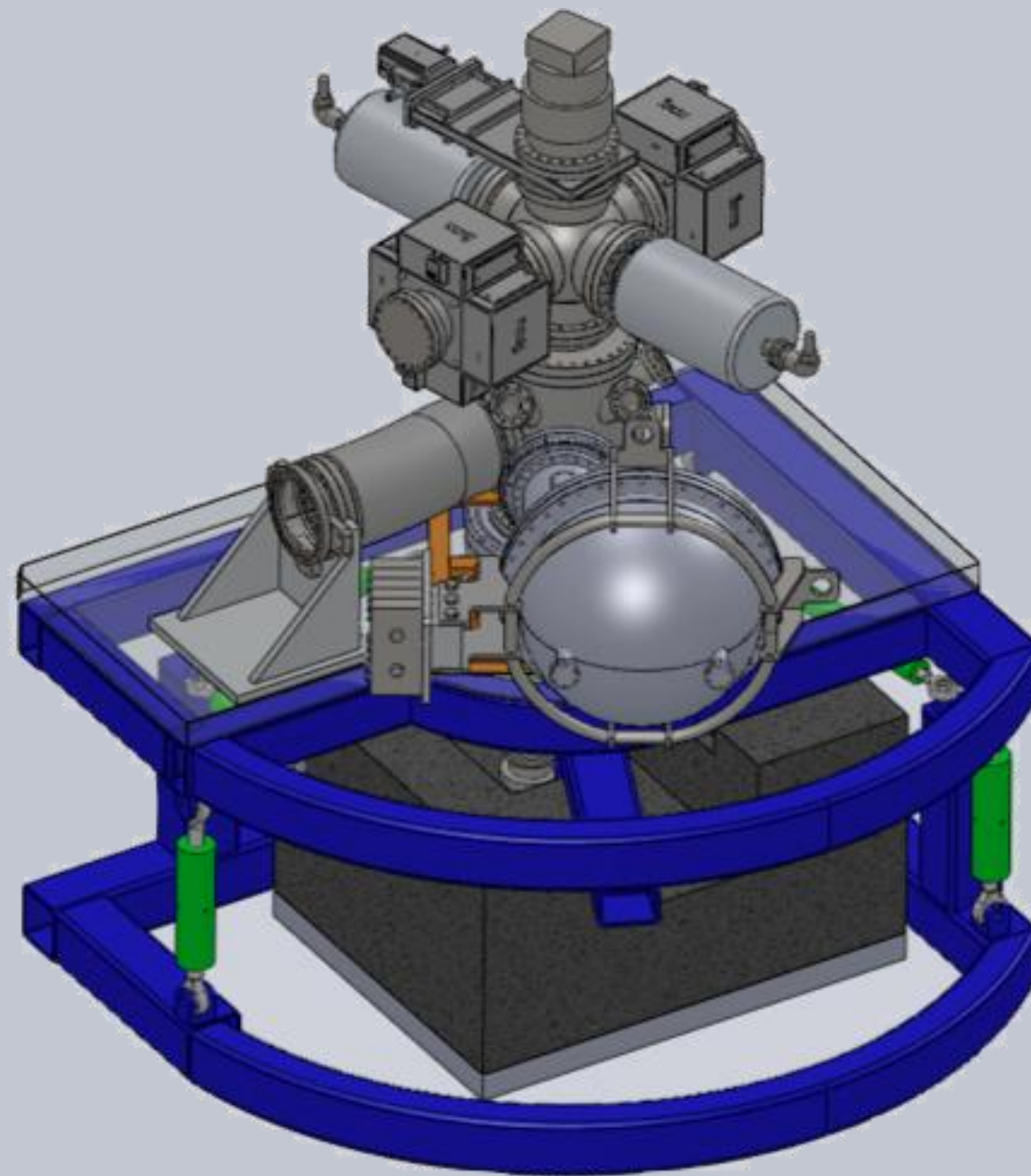
Chamber Rotation



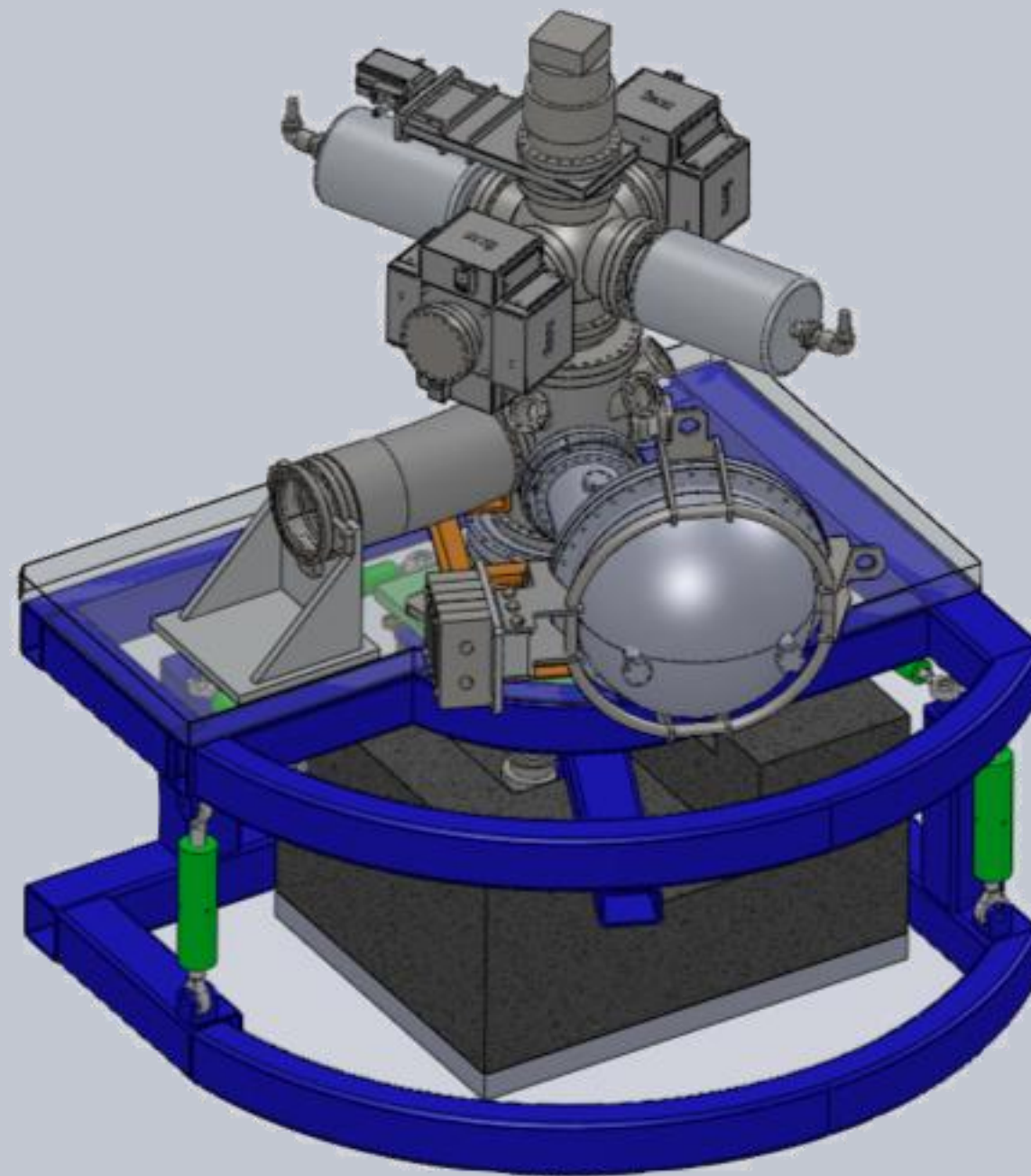
Chamber Rotation

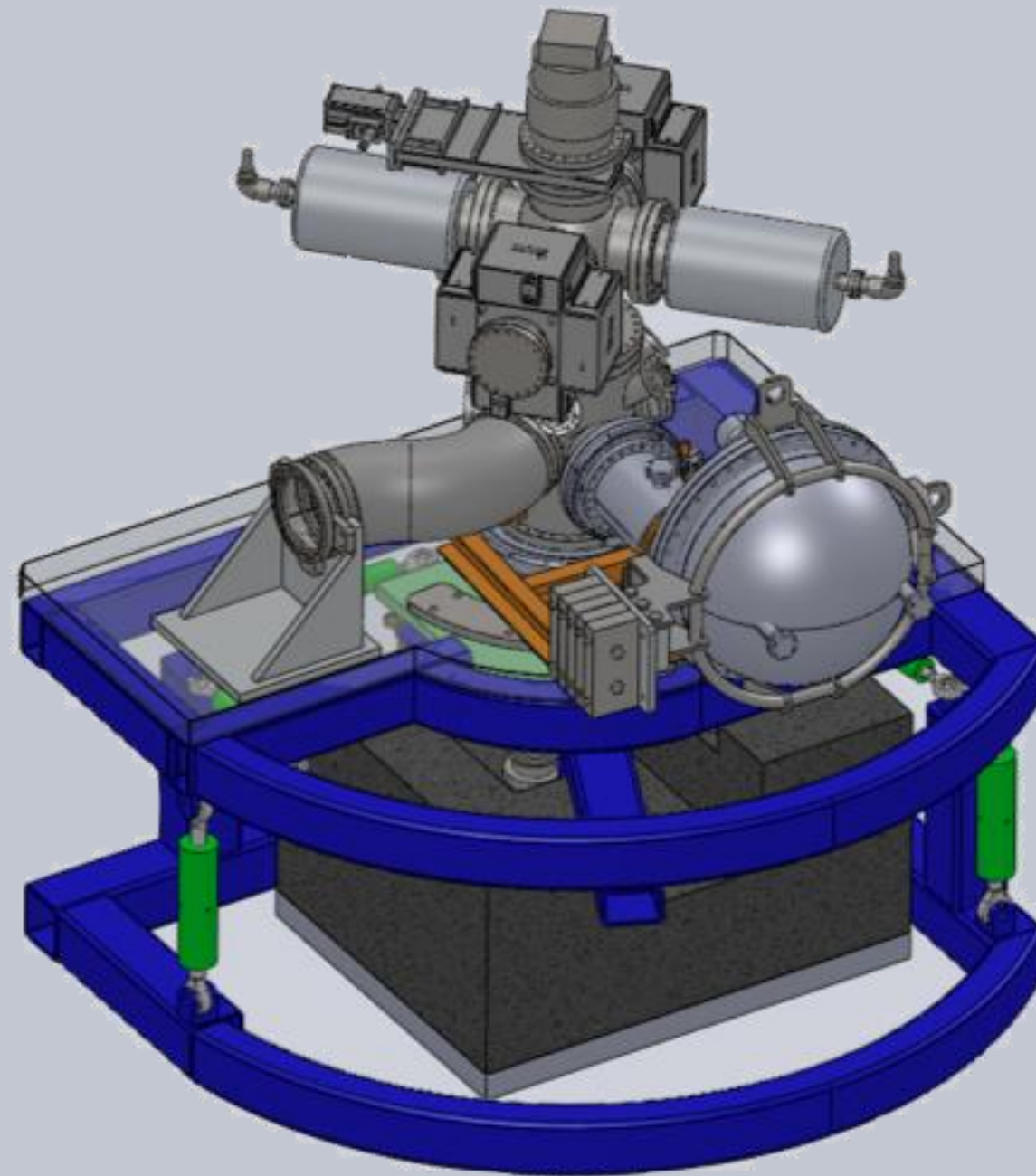




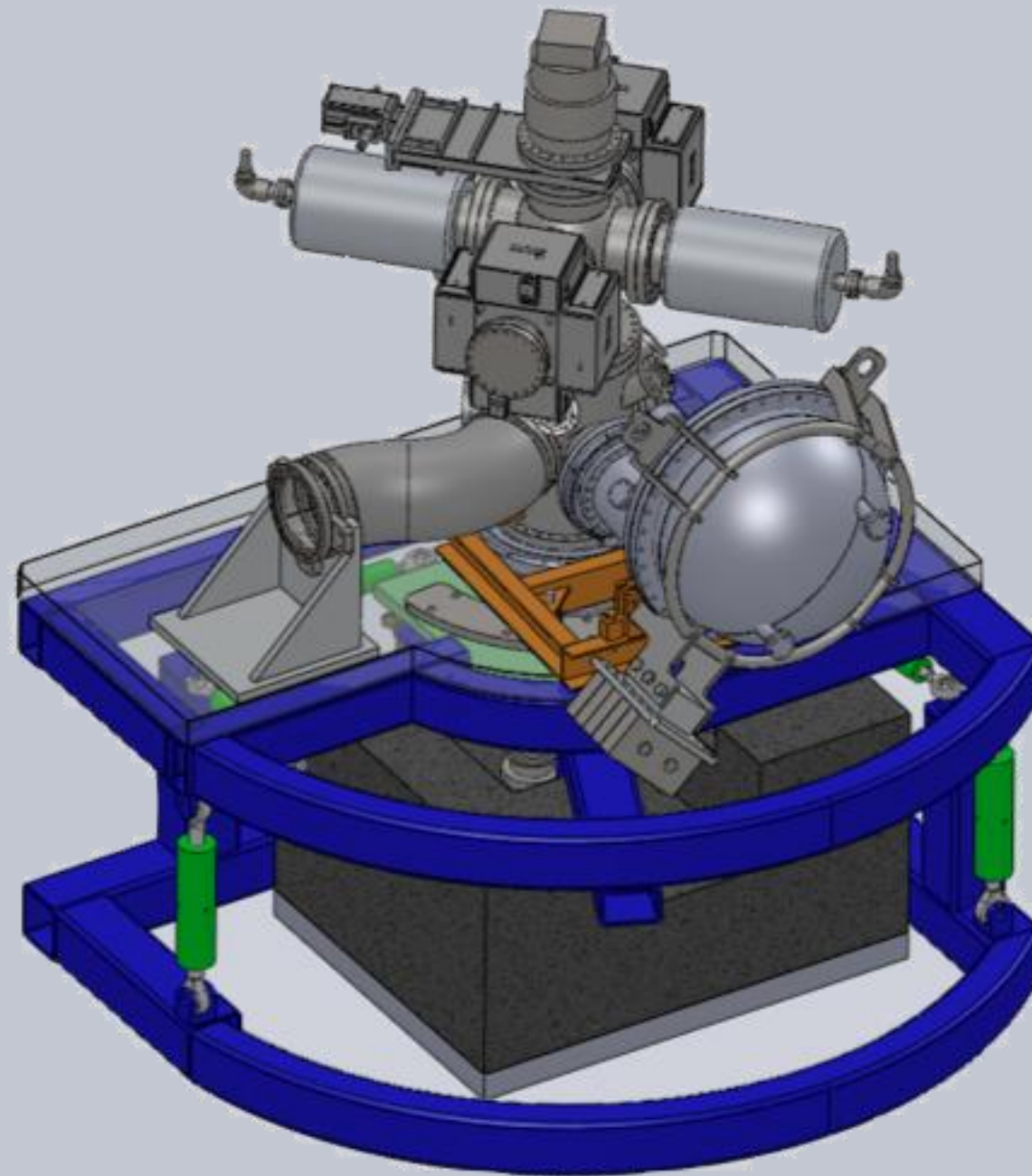


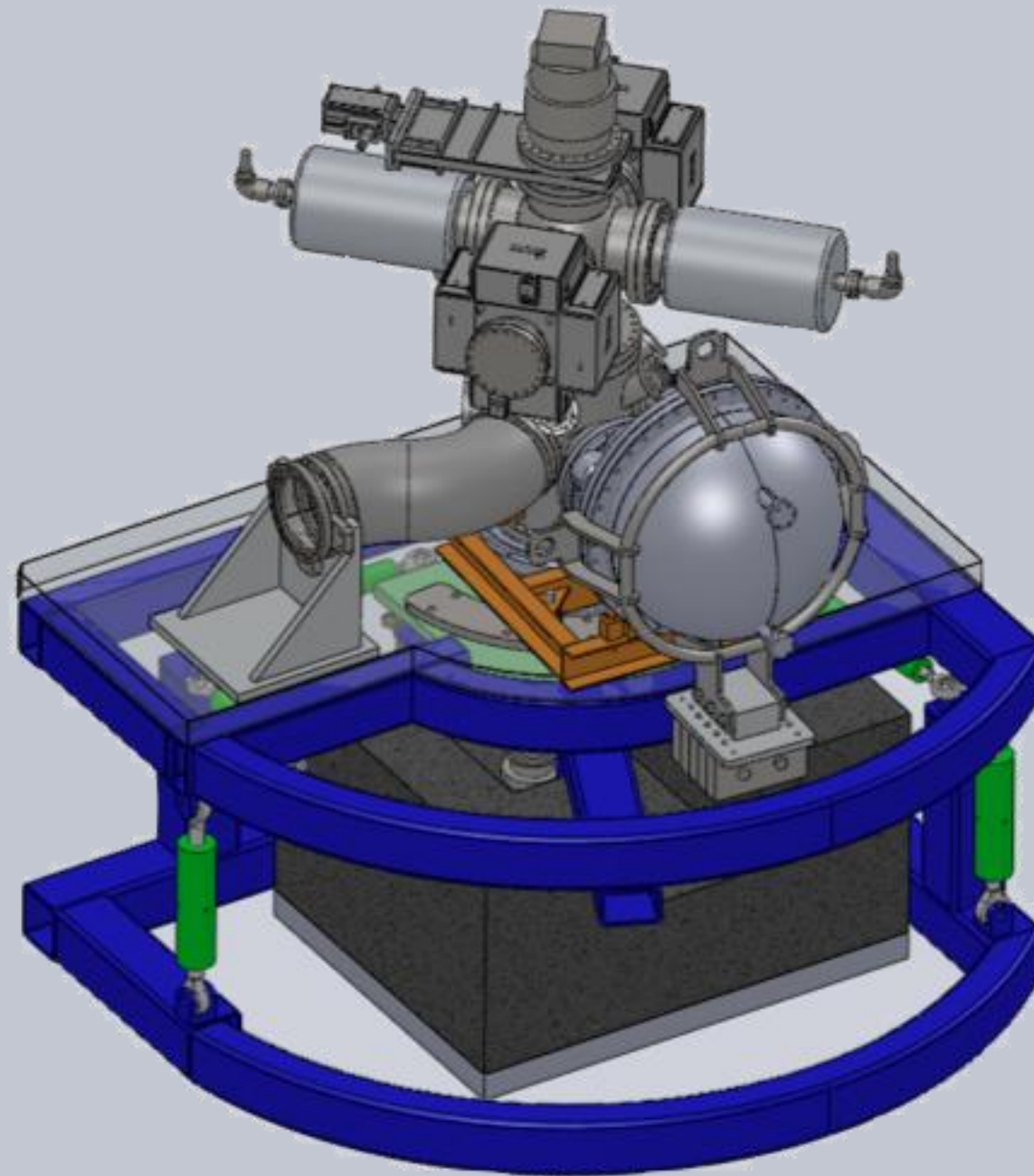
Chamber Rotation





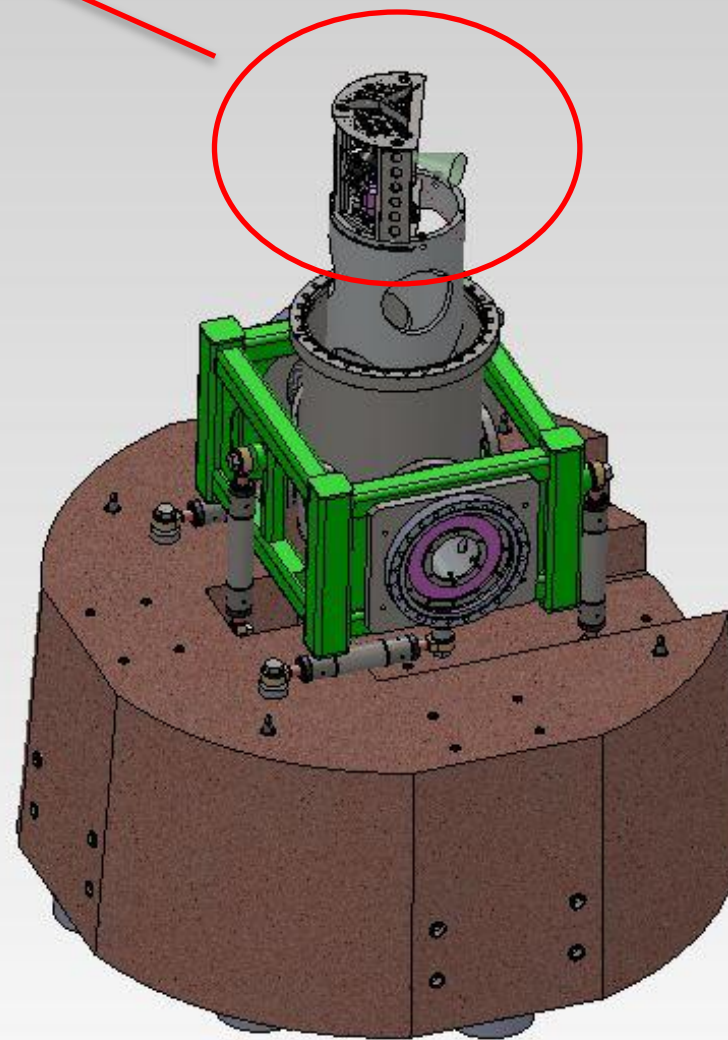
Chamber Rotation



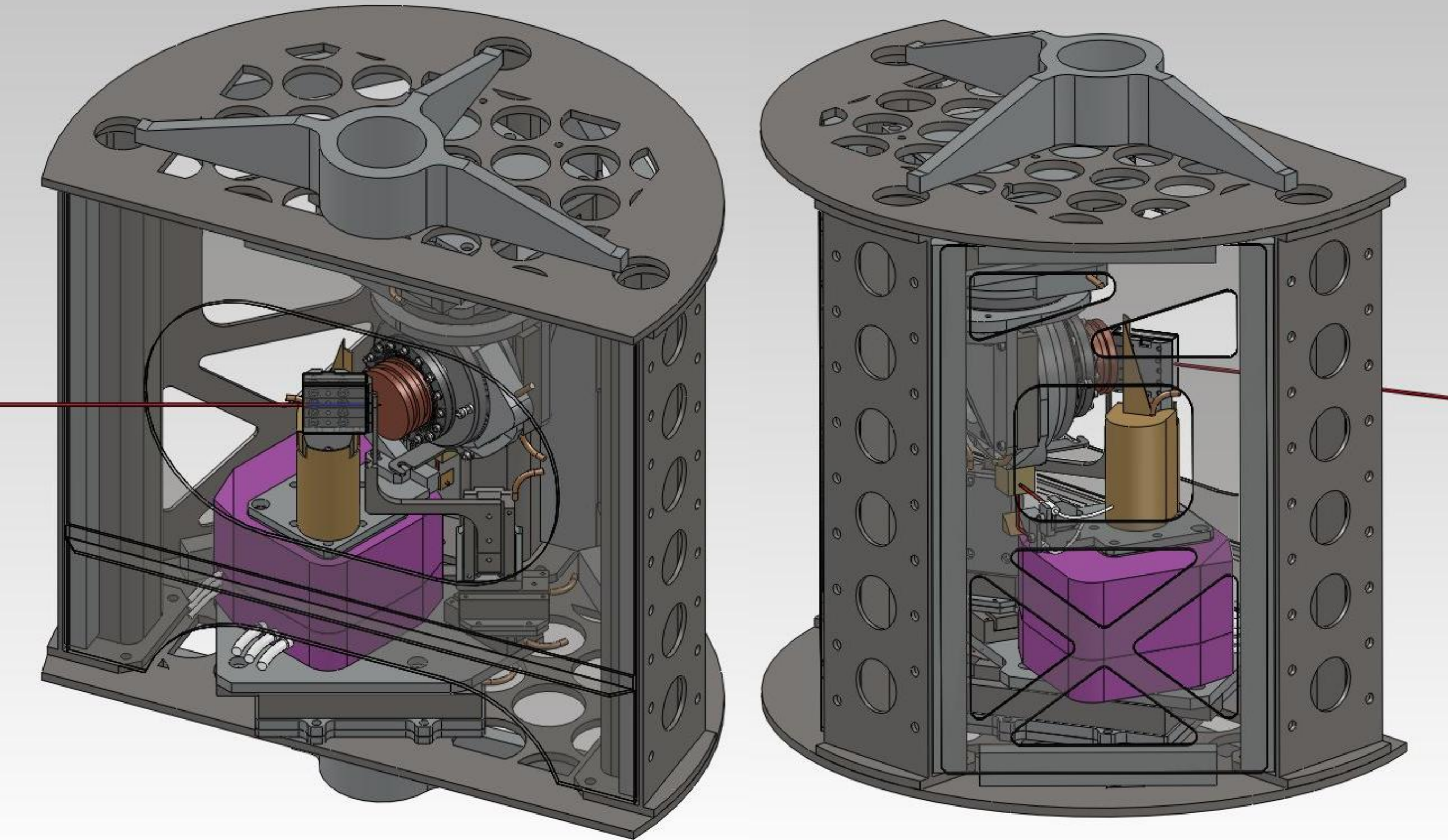


nARPES endstation

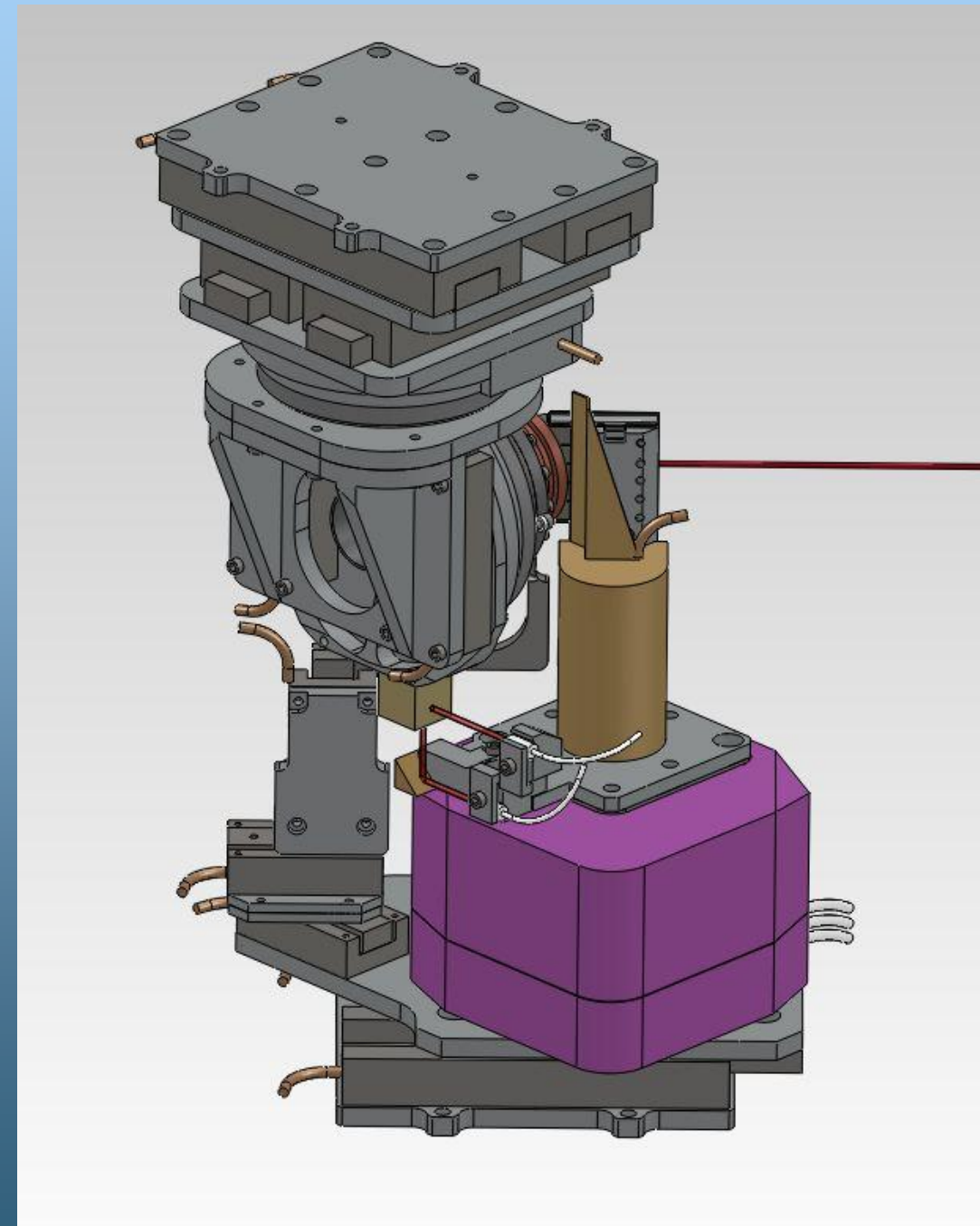
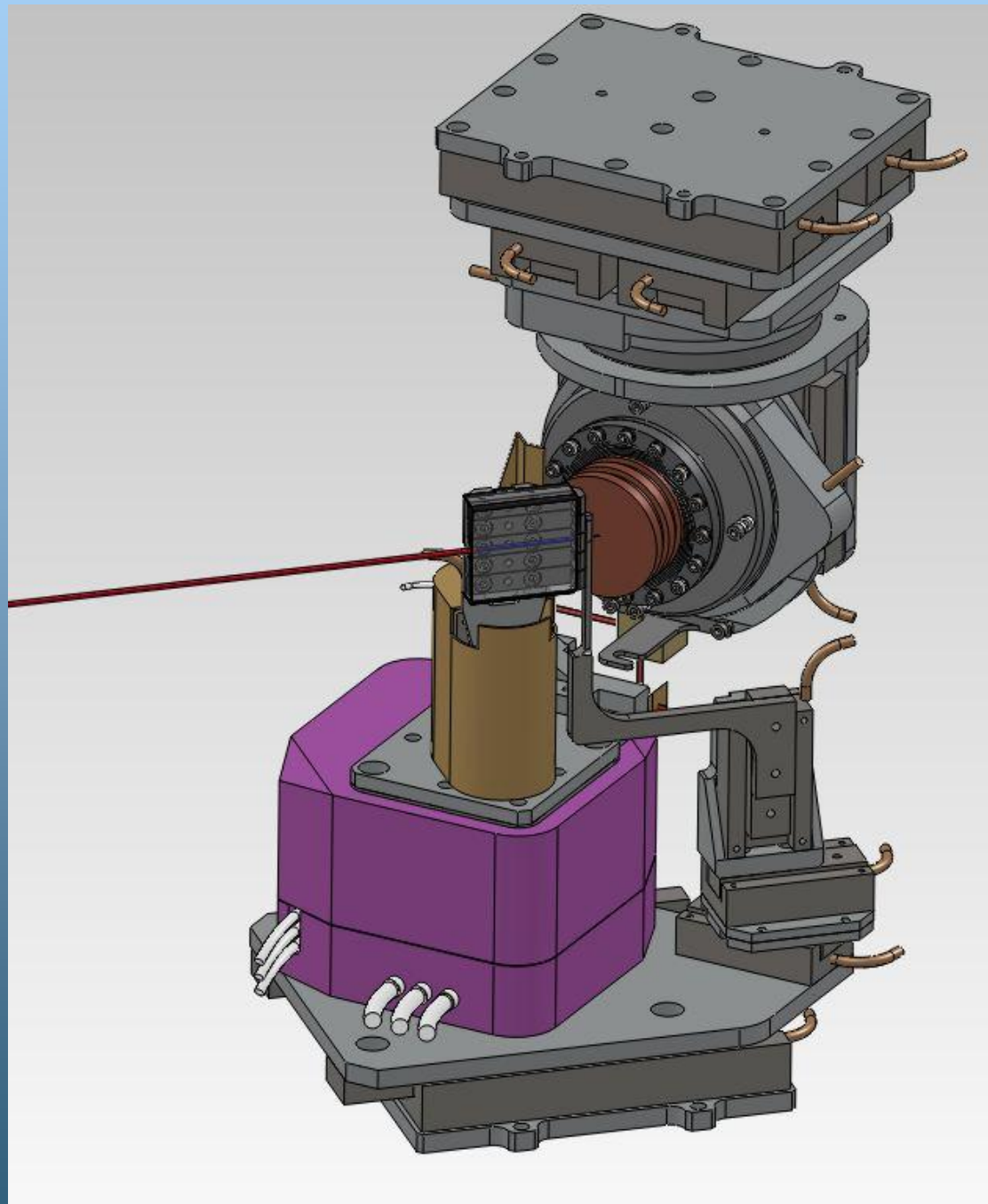
sample & optics module



SOM w manipulators



sample & optics manipulators



Summary

- One half of a chicaned sector 7 at ALS (other half is COSMIC)
- MAESTRO will include a new:
 - the next-generation nanoARPES chamber for nanometer-scale photoemission.
 - new beamline optics for sector 7, optimized for delivery of photons with sufficient flux and energy resolution to achieve down to 50 nm spot size.
 - a sample transfer system to existing preparation/characterization chambers.
- MAESTRO also integrates existing growth and characterization tools from the existing ESF facility:
 - the existing μ ARPES endstation, which will probe down to ~ 10 μm sample size.
 - the existing crystal growth chambers (MBE and laser-based).
 - a new PEEM, already funded, to be acquired in FY11.